Development and Validation of a Laminate Flooring System Sound Quality Test Method

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Development and Validation of a Laminate Flooring System Sound Quality Test Method

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NOMENCLATURE

Sound Jury (Subjective) Metrics - *Italics*

Quality
Naturalness
Pitch
Duration
Loudness

Psychoacoustic Calculated (Objective) Metrics - Bold

Loudness, N
Dynamic Loudness, N
Specific Loudness, N'
Sharpness, S
Roughness, R
Fluctuation Strength, F
Subjective Duration
Perceived Pitch
Spectral Flatness Measure, SFM

Sound Quality Index - ***Bold + Italics***

Quality
Pitch
Duration
Loudness

CHAPTER 1. INTRODUCTION

Laminate flooring manufacturers have received negative feedback from customers on the sound quality of laminate flooring installations. Customers express a preference for the sound of traditional hardwood floors over that of laminate flooring composites through comments on satisfaction. Consumers notice a difference between the sounds created by a footfall between laminate flooring and hardwood flooring. They perceive the laminate flooring sound of a footfall to be annoying and associate it to the flooring being of a lower quality. No objective test procedure exists to validate the marketing claims of the performance of these products. The objective of the work in this thesis is to develop a test method that evaluates the human perception of the sound quality of footfall noise on laminate flooring composites. The following sections of this chapter introduce the background on flooring and the human perception of sound, a note concerning nomenclature conventions used in this thesis, a review of relevant studies pertinent to this work, and a detailed overview of the objective and approach used in this thesis.

1.1 Background

The purpose of this section is to review the basics of flooring composites, psychoacoustics, and sound quality. The background material in this section is needed to understand the material presented in the following chapters. Section 1.1.1 presents the materials that comprise laminate flooring composites, as well as competitive flooring materials. Section 1.1.2 presents the basic relationship between physical acoustics and the human perception of sound.

1.1.1 Introduction to Flooring

Hardwood and laminate flooring composites are found in a wide variety of installation types and usages. The materials and installation methods used in the installation of the flooring assemblies vary considerably. The most common types of laminate and hardwood flooring and their installation methods are described. Schematics of flooring composites with all associated components are given in Figure 1. A typical flooring system comprises multiple layers, including flooring material (e.g. hardwood or laminate), an underlayment (e.g. foam or felt), and a subfloor (e.g. concrete slab or wood frame). A variety of mounting conditions can be used, depending on the materials comprising the flooring assembly. As shown in Figure 1 (a), laminate and engineered flooring installed on a wood frame subfloor may be installed in either a floating or glue-down installation. Engineered hardwood floors on a wood frame subfloor may also be installed in a nail-down or staple-down installation as well. As shown in Figure 1 (b), laminate and engineered flooring installed on a concrete slab may be installed in either a floating or glue-down installation. As shown in Figure 1 (c), hardwood floors on a wood frame subfloor are traditionally used with a nail-down or staple-down installation, but glue-down installations can be used as well.

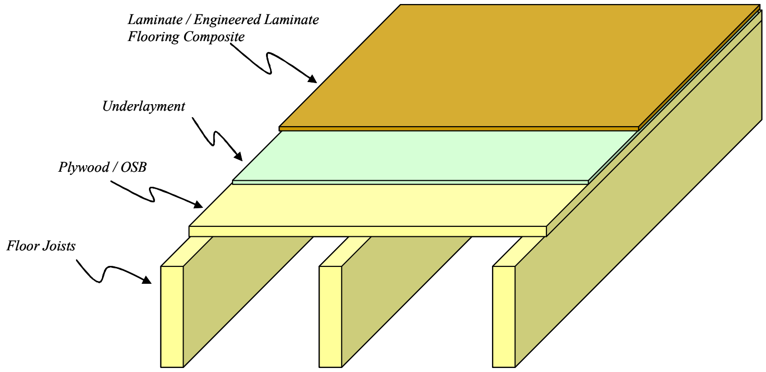

Figure 1 (a): Laminate and engineered flooring with underlayment on wood frame construction

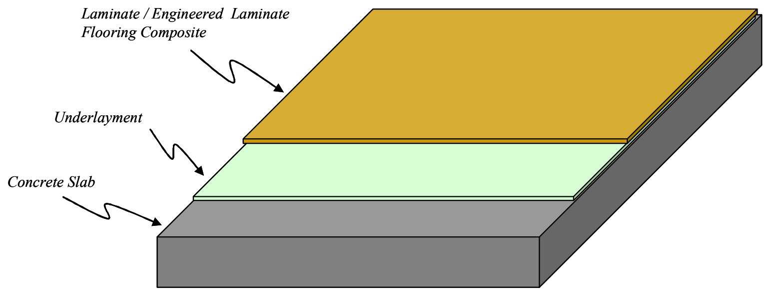

Figure 1 (b): Laminate and engineered flooring with underlayment on concrete slab construction.

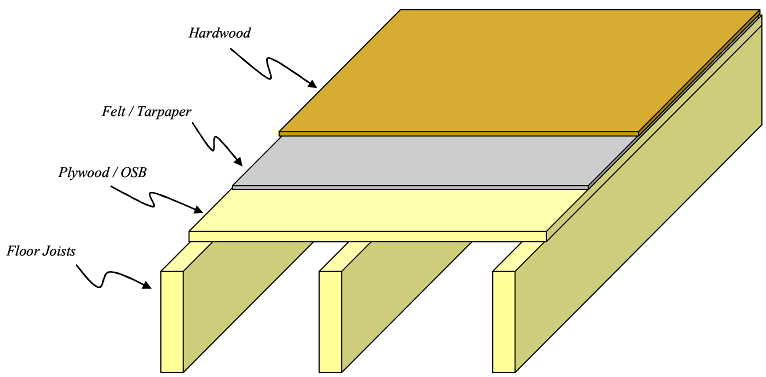

Figure 1 (c): Hardwood flooring with felt/tarpaper on wood frame construction.

Figure 1: Schematics of common flooring installations for hardwood and laminate flooring.

1.1.1.1 *Flooring Types*

Three of the most common surface materials used in hardwood-flooring-type installations are traditional hardwood, engineered hardwood laminate, and laminate. Hardwood floors are milled from a solid piece of hardwood, typically oak, and cut to various lengths and thicknesses. Schematics of each flooring plank type are shown in

Figure 2. Engineered hardwood laminate floors are made of a laminate between a thin surface layer of hardwood, with a plywood backing. Laminate flooring is comprised of a melamine wear layer laminated to a particle board backing with a printed pattern layer in between. A thin layer of melamine on the back side is common and ensures a flat plank.

Figure 2 (a): Hardwood floor plank construction consisting of a solid piece of hardwood.

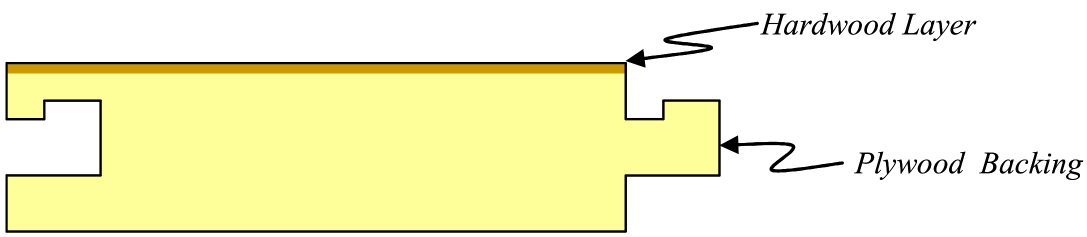

Figure 2 (b): Engineered floor plank construction consisting of a thin layer of hardwood over a plywood backing.

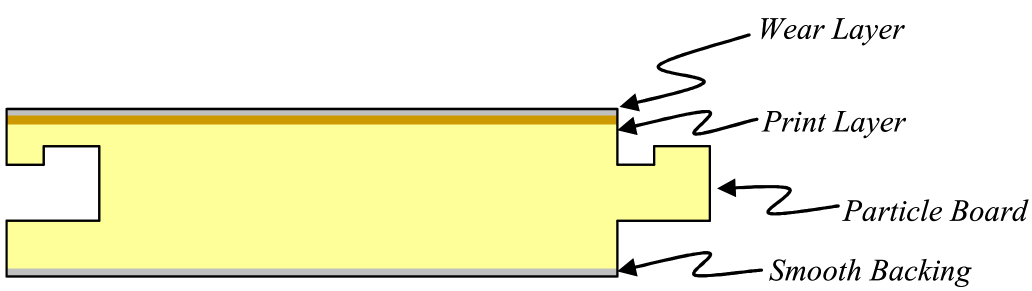

Figure 2 (c): Laminate floor plank construction consisting of a thin wear layer over a patterned print layer with a particle board core and a smooth backing layer.

Figure 2: Flooring material schematics of hardwood, engineered hardwood, and laminate planks.

1.1.1.2 *Underlayment Types*

Underlayments are installed beneath laminate flooring. The purpose of installing an underlayment is to reduce noise, thermally insulate the floor, and provide a moisture barrier between the floor and the subfloor. Underlayments are made from a variety of materials. Oftentimes, the underlayments are layered composites, where the manufacturer laminates several materials together to give good properties in the three categories listed above [1]. Common underlayments include foams, felts, cork, and rubber. Foam underlayments are made from a variety of foam types. The most economical option is an open cell foam, roughly 1/8" thick. Upgraded foams are common, but more expensive. They can be a similar foam, but of greater thickness, closed cell instead of open cell, or a foam of higher density. All of these foam products are potentially offered with a vapor barrier, so that they may be installed on concrete slab subfloors [1]. Felt materials are also used in underlayments. Felts tend to have a high percentage of voids in the material, which allows the underlayment to achieve good sound isolation [2]. Cork underlayments are expensive, relative to the more common underlayment materials. Corks are typically 1/4" thick and are used in glue down installations. They are known for having a high level of sound isolation and are often required in multifamily housing laminate installations [1]. Rubber underlayments are used in both floating and glue down installations for all types of laminate flooring. Rubber underlayments come in a number of thicknesses up to approximately 1/2" thick [1].

1.1.1.3 *Subfloor Types*

The base of a floor is referred to as the subfloor. Subfloors are the structural element of a floor or a layer placed on top of the structural members in a floor. A concrete slab subfloor is a layer of concrete, which may be suspended in the air, as in a second floor of a building or on pilings or directly slab-on-grade. Concrete subfloors are several inches thick and may have steel rebar reinforcement [3]. Wood frame subfloors are built with a plywood or oriented strand board surface layer nailed to a wood frame structural element. The structural element may be a number of wood sizes, such as 2x4's and 2x10's, as well as engineered wood I-beams [3].

1.1.1.4 *Flooring Mounting Conditions*

Floors may be mounted to subfloors using a number of methods. Flooring products can be installed on concrete subfloors by gluing the underlayment and flooring material. Most commonly, underlayments and flooring materials are installed over concrete in a floating installation, where no permanent attachment to the subfloor is used. Underlayments for wood frame subfloors can be installed by glue-down or nail-down, as well as floating. Glue-down and floating installations on a wood frame subfloor are mounted in the same manner as a concrete slab subfloor. Nail down installations offer a fixed condition similar to a glue-down, using nails as the attachment method rather than an adhesive [3].

1.1.2 Human Perception

Determining the sound quality of impact sounds on laminate flooring required an analysis focused on the human perception of that sound. Traditionally, the analysis of sound within the field of acoustics used signal processing techniques to quantify physical characteristics of the signal. More recently, the field of psychoacoustics began to quantify the human perception of sound using signal processing specifically developed to mimic the response of the human auditory system. The human auditory system consists of the human aural system, as well as the signal processing that occurs in the brain, known as the central auditory system. After psychoacoustic measures were developed to represent the human auditory response of an acoustic signal, investigators began to use the psychoacoustic metrics to quantify the sound quality of sounds through sound jury experiments.

Sound quality is often not an inherent aspect of a product. It is often the result of a consumer's expectation of a product based on previous use of similar products. When comparing the sound of a product to their expectation of sound for the product, the ability of the product to meet that expectation determines the sound quality. Sound quality efforts often involve benchmarking a product that is perceived to be of high quality [4]. Similarly, the determination of the sound quality of laminate flooring composites was established using psychoacoustic metrics. The relevance of different psychoacoustic metrics to the perception of sound quality can be established using a sound jury. From the wide variety of psychoacoustic metrics that exist, a sound jury is needed to determine which characteristics of a sound and their corresponding metrics influence the perception of sound quality. A sound quality index is commonly used to represent the perceived sound quality of an acoustic signal. The sound quality index is a regression model fit of all relevant objective psychoacoustic metrics [5].

1.2 Nomenclature

In this thesis, a number of terms were used in more than one way. A formatting convention was used to allow the reader to clearly differentiate between the usages of the terms. The full list of all of the terms is presented in the foreword of this thesis. All of the metrics that were evaluated by jurors to describe their perception of the sounds during the sound jury are in *italics*, such as subjective *Quality* and subjective *Pitch*. All objective calculated psychoacoustic metrics are in **bold**, such as objective **Loudness** and objective **Sharpness**. All sound quality indices constructed from the results of the sound jury and calculated psychoacoustic metrics are ***bold and italicized***, such as ***Quality*** and ***Pitch***.

1.3 Prior Work

The purpose of this section is to present a review of prior work relevant to the development and validation of a laminate flooring system sound quality test method. Studies done in the relevant areas of floor impact sound, sound quality models, walking sound impact methods, and the radiation of rigid plates are discussed.

1.3.1 Floor Impact Sound

Prior work to develop an objective test method to evaluate the human perception of laminate flooring objective **Loudness** was conducted by the European Producers of Laminate Flooring (EPLF). The EPLF conducted a study to evaluate the objective **Loudness** of impact walking sounds from flooring composites. The study constructed small scale laboratory samples of flooring composites and used a floor tapping machine to generate an impact on the floor. A tapping machine consists of several impact heads on a rotating shaft, which impacts the floor several times per second to generate impact sound. The objective **Loudness** of the floor was used as the metric to evaluate the performance of the floor relative to a reference floor sample. The study utilized the objective **Loudness** metric over that of traditional sound pressure level. The purpose of using the objective **Loudness** metric was in to better capture the human perception of the sound created by the floor. The study did not attempt to characterize the sound quality of the flooring composites, but specifically addressed the area of sound quality as the focus of future work [6]. The significance of this study was that it was the first attempt to use an objective psychoacoustic metric to quantify the performance of flooring composites, rather than standard acoustic measures, such as sound pressure level.

In 2008, Empa, a research institute in Switzerland, conducted a similar study for the EPLF to study subjective pleasantness and objective **Loudness** of human walking sounds on laminate flooring composites as a way to quantify the sound quality. The Empa study was the next logical step in an effort to understand the human perception of flooring composites. The objective of the study was to correlate the human perception of the floor impact sounds to objective metrics. The study included a sound jury panel to evaluate the subjective pleasantness and objective **Loudness** of the flooring composites. The study replaced a tapping machine in favor of a calibrated walking shoe with a transducer to measure the walking force profile. The subjective performance of each flooring composite was rated by the sound jury and compared to objective metrics. The results of the study showed that the subjective pleasantness of the flooring composites correlated well with the objective **Loudness** and objective dynamic **Loudness** measurement, with the objective dynamic **Loudness** measurement slightly outperforming the static objective **Loudness** measurement [7]. The significance of this study was that it conducted a sound jury to relate the subjective performance of flooring composites to that of an objective metric.

1.3.2 Sound Quality Index

In a study conducted at University of Salford, a detailed product sound quality assessment of a washing machine is presented [8]. The washing machine study provided a detailed framework for constructing a sound quality index from objective psychoacoustic metrics and subjective sound jury results.

Washing machine sounds were presented to a sound jury, so that the human perception of the sounds were known. The data from the sound jury was normalized and then correlated to show relationships between the different metrics. Significant correlations were established from the number of degrees of freedom in the study and the resulting critical correlation level. Next, an analysis of variance calculation, or ANOVA was performed. The ANOVA determined whether or not the relationship between the variables was statistically significant and whether or not the differences between all of the samples in the study were significant. Finally, a multiple variable regression analysis was performed. A pleasant washing machine was shown to be "one that is quiet, one that sounds robust (strong) and one that is of high quality" [8]. The specific weightings for the regression analysis were not provided.

1.3.3 Impact Method

Prior work in the area, performed by the EPLF and discussed in Section 1.3.1, utilized standardized floor impact test hardware, such as the tapping machine used in *ISO 140-8: Acoustics. Measurement of sound insulation in buildings and of building elements.*

Laboratory measurements of the reduction of transmitted impact noise by floor coverings on a heavyweight standard floor [6]. The Norsonic N-277, as shown in Figure 3, is a common model floor tapping machine. The benefit of using this device was that it was already accepted and widely used in industry. The tapping machines created sound by repeatedly impacting the floor with six mandrels mounted on a rotating shaft.

Figure 3: Tapping machine in use during EPLF sound quality study [7].

However, there were problems associated with using the floor tapping machine for sound quality testing. The tapping machine was a mechanical device and has background noise associated with its operation. Furthermore, the background noise may be variable, depending on which manufacturer's tapping machine is being used. Because the background noise of the unit was not of importance when using the tapping machine in its original intended purpose of between building floor impact noise, it is not a controlled specification. Additionally, testing showed that different tapping machines have different radiation patterns associated with them [9].

Another option for impact testing was to use actual human footsteps. Because the desired effect of the impact method was to create an impact sound representative of footfall sound, using a human footfall as the excitation method was a logical choice [10]. The Empa procedure, presented in Section 1.3.1, employed the footfall method using a known heel hardness shoe sole and force transducers to measure the impact [7]. The shoe used in the Empa tests is shown in Figure 4.

Figure 4: Sound quality floor impact walking shoe with controlled heel hardness used in Empa study (98 Shore A) and a transducer to measure the impact [7].

In a study conducted at the State University of New York at Binghamton to determine the sex of a human based on the sound of their walk, differences in foot strike frequency content were found. Figure 5 shows these differences. The left column consists of the frequency content of male walkers and the right hand column consists of female walkers. Differences are observed both within groups of male and female walkers and between the groups of male and female walkers [11].

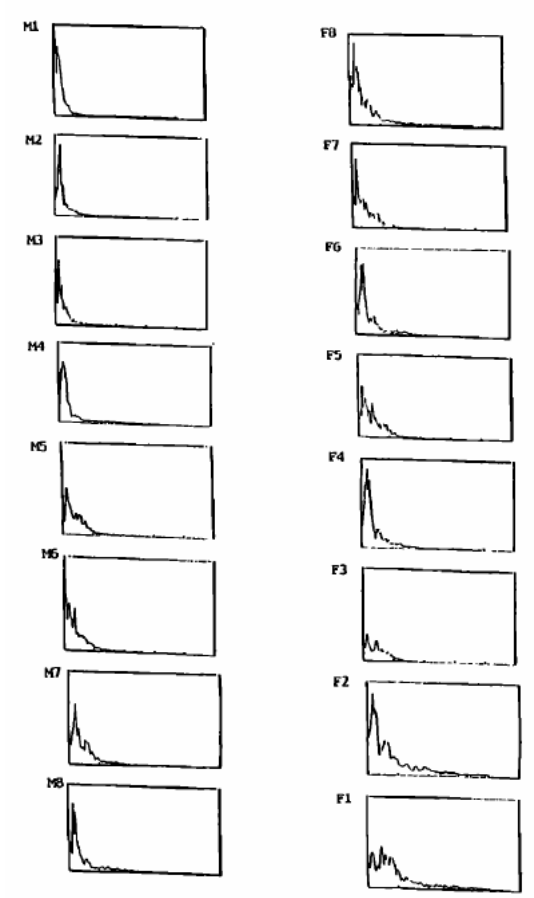

Figure 5: Frequency spectra for 8 male (left column) and 8 female walkers (right column) [11].

The human footfall method was a natural choice for sound quality of flooring testing, because it was a direct representation of footfall noise. At the same time, there are two critical issues. First, the impact device needed to be consistent from lab to lab as well as between individual tests. Maintaining this consistency was accomplished by specifying the properties of the impact shoe with adequate detail, so that an identical shoe could be used in each lab's own testing. The second issue of how to control the spectrum created by a walker was not addressed. Studies have shown that an individual's footfall is unique, and the uniqueness can observed above in Figure 5. Successfully standardizing a human footfall for repeatable testing across several labs is not realistic [6]. Human foot strikes change as the style of walking changes from that of a casual walk to a brisk walk. Within a consistent type of walk, generated sound changes from individual to individual [12]. Additionally, gender differences have been be observed in walking styles [11]. Consequently, there is no one specific footfall impact spectrum.

A study conducted at the University of Applied Sciences in Stuttgart Germany investigated the walking sounds on lightweight stairs. One aspect of the study was to find the correlation between real walking sounds and simulated walking sounds for tapping machines and ball drop impacts, which utilized a ball dropped from a specified height to impact the floor. Both a standard tapping machine and a modified tapping machine with different tapping heads were used as described in *ISO 140-11: Laboratory measurements of the reduction of transmitted impact sound by floor coverings on lightweight reference floors*. The correlation between the artificial impact techniques and real walking sounds of high-heel shoes was provided. In this particular study for stair noise, the stock tapping machine had generally poor performance, while the modified tapping machine was greatly improved. The ball drop impact performed well in terms of objective L**oudness**. The metrics of objective **Fluctuation Strength** and objective **Roughness** were not as strongly correlated. The objective **Fluctuation Strength** of the ball drop did perform better than the standard and modified tapping machine [13].

Table 1: Correlation of several artificial footfalls to high-heel shoe walking sounds [13].

Metric	Tapping Machine	Modified Tapping Machine	Rubber Ball
Loudness	0.68	0.96	0.94
Fluctuation	-0.12	0.64	0.74
Roughness	0.38	0.68	0.58

If a repeatable impact such as a tapping machine or a ball drop is used, then a less than perfect reproduction of human footfall noise is an unavoidable consequence. Based on the results of the study in Stuttgart, the modified tapping machine and the ball drop both perform similarly well in terns of correlating objective psychoacoustic metrics to real human footfall impact sound.

1.3.4 Floor Radiation Pattern

The flooring composites subject to impact sounds as discussed in the EPLF and Empa studies are likely to function as vibrating plates. The potential modal response of the flooring composites may be significant. In a study of the modal response of square metal plates, the distinct modal response of a rigid plate with a fixed boundary condition at each corner can be observed in Figure 6.

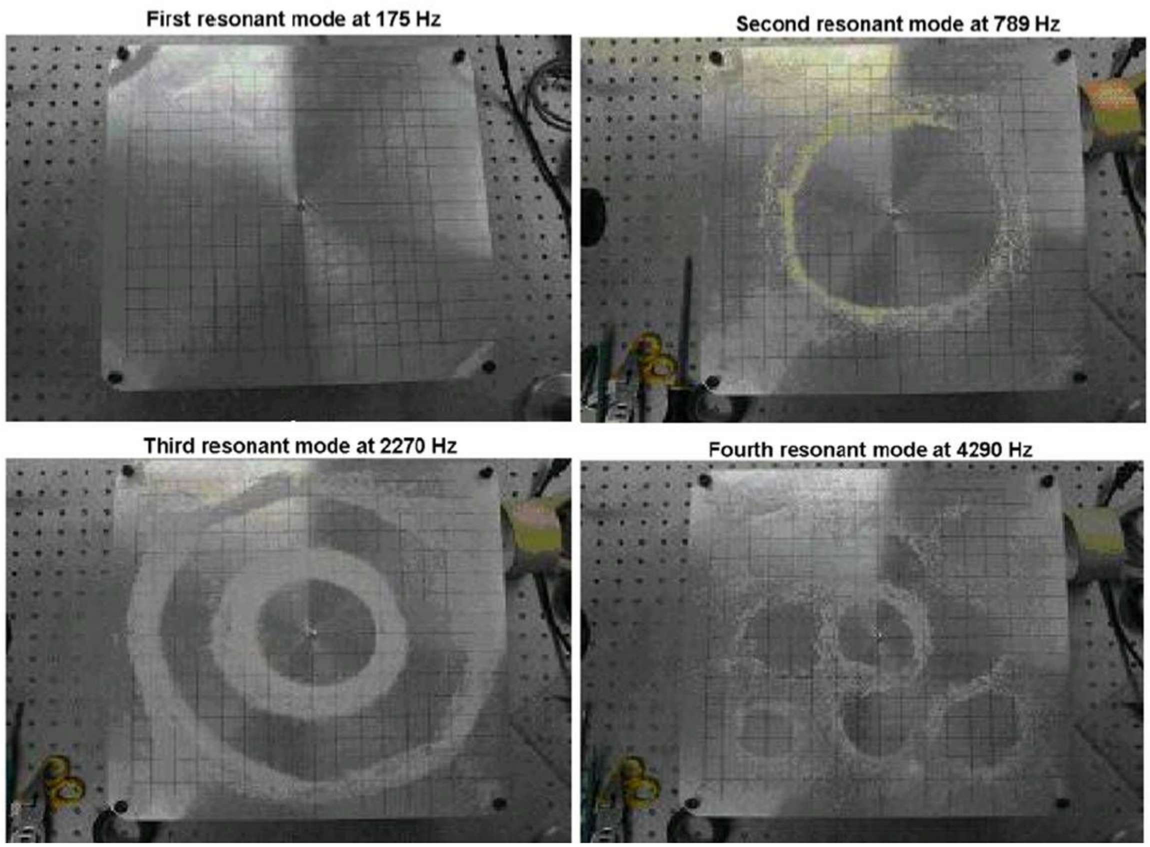

Figure 6: Modal response of a metal plate for its first four natural modes [14].

Flooring composites may act as rigid plates, similar to the metal plates shown in Figure 6. The modal response of the flooring composites should be investigated to determine the effect of microphone placement on the measured sound field.

1.4 Objective and Approach

The objective of this thesis was to develop a test method to evaluate the sound quality of laminate flooring relative to traditional hardwood flooring installations for footfall impact sound. An objective test method was sought to evaluate these products in their acoustical sound quality performance. The validity of the objective test method was established by conducting a sound jury to correlate the human perception of the flooring composite flooring to statistically significant objective psychoacoustic metrics.

As introduced in the prior section, the investigation of the sound quality of laminate flooring required flooring test articles, a means to emulate and record footfall sounds, the conduction of a sound jury to assess the sound quality of the impact sounds, and the development of a sound quality index that captures the relevant psychoacoustic metrics. The objective of the thesis was met by executing the work as shown in an overview of the project, provided in Figure 7. The preliminary work was conducted to determine the proper sound jury procedure and relevant objective psychoacoustic metrics that were used for the specific problem of walking sound on flooring sound quality. Additionally, work was conducted to understand the physical issues that may arise in the acoustical radiation of flooring composites and to resolve an acceptable impact method for laboratory testing. After the preliminary work was complete, samples were constructed to mimic real world flooring and tested in the prescribed laboratory procedure. The recordings of the impact sounds were presented to a sound jury for evaluation and processed using the relevant objective psychoacoustic metrics. The statistical relationships between the subjective sound jury perceptions and the objective psychoacoustic metrics were used to create sound quality indexes that describe the human perception of the floor impact sounds. The sound quality indexes were constructed using objective metrics that were shown to be statistically related to the subjective perception.

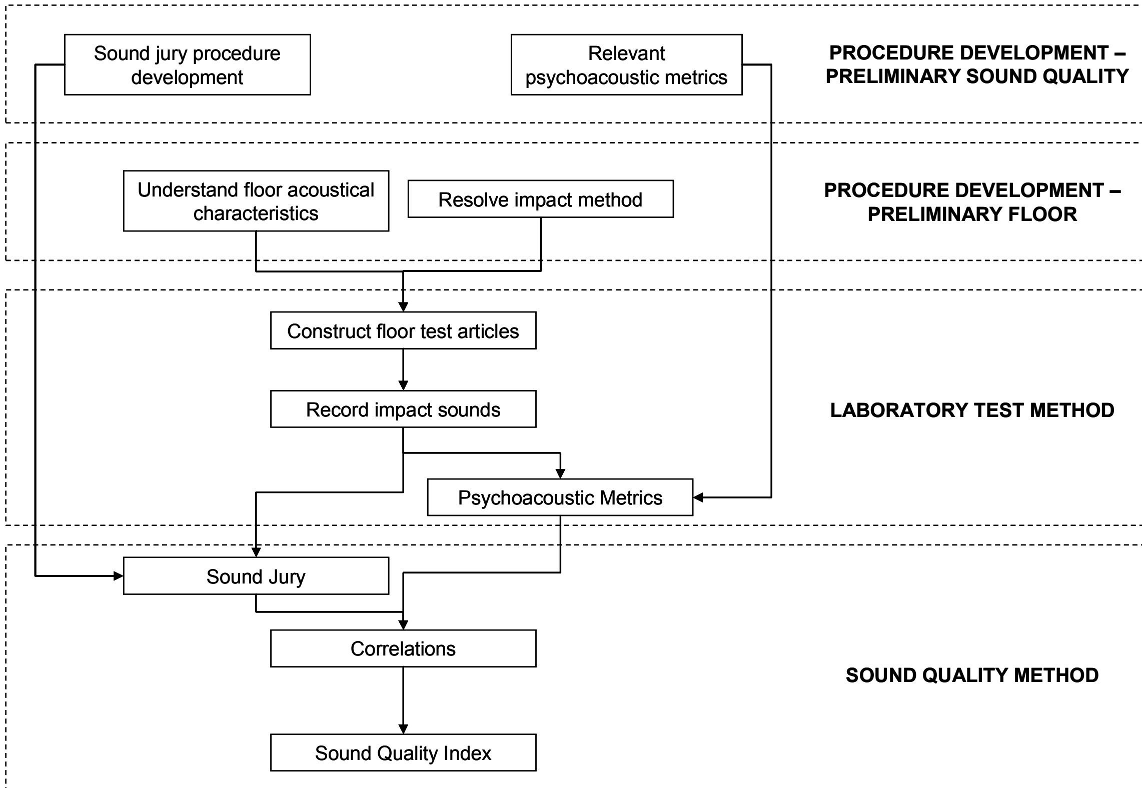

Figure 7: Sound quality of laminate flooring project overview.

CHAPTER 2. HEMI-ANECHOIC CHAMBER AND DATA ACQUISITION SETUP

The purpose of this chapter is to present the hemi-anechoic chamber and data acquisition hardware used in all of the testing in this thesis. The setup presented in this chapter is used in all recordings.

2.1 Hemi-anechoic Chamber

The recording environment for all samples used in the study was the hemi-anechoic chamber on the Georgia Institute of Technology campus, which is part of the Integrated Acoustics Laboratory (IAL). Preliminary testing of the capability of the chamber for flooring impact testing called for a background noise level study. The measured background noise of the hemi-anechoic chamber is shown in Figure 8. The Noise Criteria (NC) method was used to determine if the background noise was suitable for this type of study. The background noise in the hemi-anechoic chamber was below the noise requirement of a NC-25 space. A NC-25, which encompasses rooms such as bedrooms and quiet conference rooms, is adequate for recording the samples for this study, because it falls below standard ambient noise level criteria for environments where the flooring products tested in the study are found (e.g. homes and office spaces) [15]. A Larson-Davis 824 sound level meter was used to find the A-weighted equivalent sound pressure level background noise, which was found to be 21 dB.

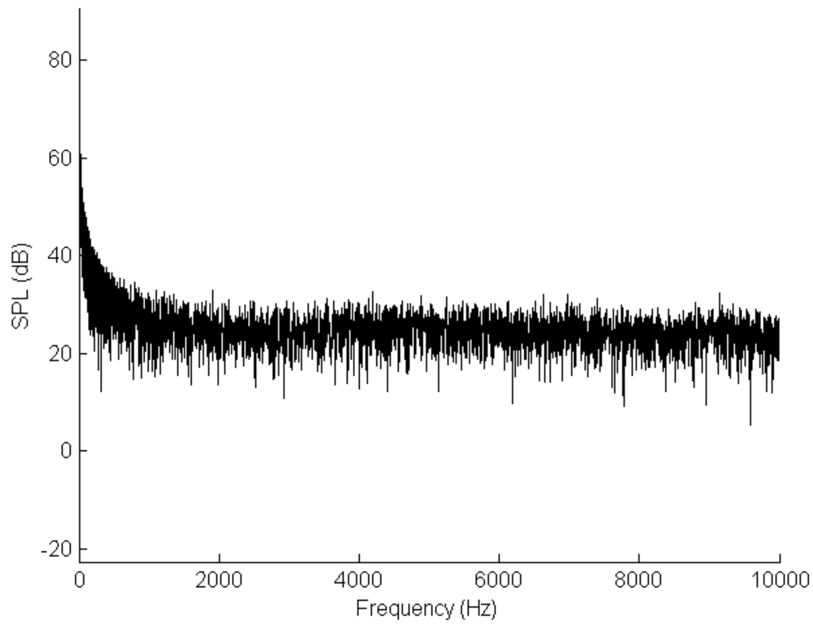

Figure 8: Hemi-anechoic chamber background noise sound pressure level (SPL).

2.2 Data Acquisition Setup

The recording hardware used in the hemi-anechoic chamber is shown in Figure 9. LMS software was used in all of the data acquisition. However, the raw time versus pressure data was exported and processed using MATLAB, which is discussed in Section 2.3.

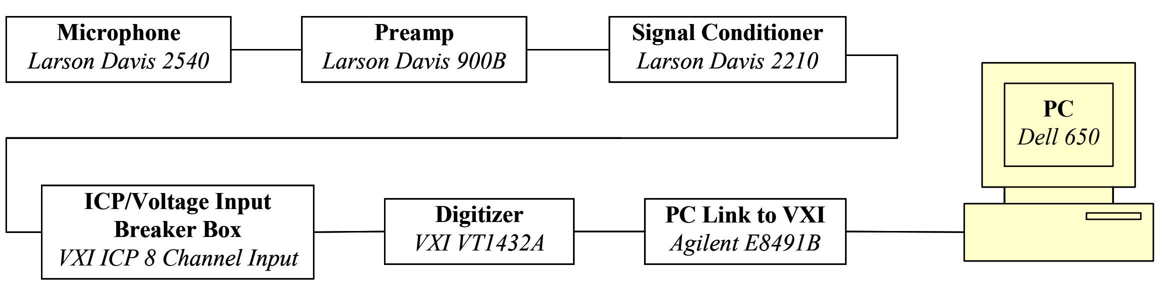

Figure 9: Data acquision system used to record samples.

The sampling rate used in all recordings was 25600 Hz, and a total of 4096 samples were used. Each flooring sample was recorded 5 times, so that the repeatability of the measurement could be calculated. The repeatability results are presented and discussed in Section 3.2.1.

2.3 Sound Jury Sample Preparation

All samples used in the sound jury were converted to a .wav format for listening. The samples were recorded in LMS and exported in ASCII format from LMS. The file extensions were relabeled to a MATLAB file (.m). Next, the time and pressure data contained in the files were converted to .wav files using MATLAB. The program used to perform the conversion is provided in Appendix IX.

CHAPTER 3. PROCEDURE DEVELOPMENT

This chapter presents material that was investigated before the actual experimental procedure could be developed, as described in the introduction. Section 3.1 presents the psychoacoustic metrics that may be relevant in short-time impact signals as well as proper sound jury techniques that should be followed to obtain good quality data from a sound jury. Section 3.2 presents preliminary studies that were conducted to understand specific issues associated with simulating human footfall in a laboratory environment, specifically creating a suitable artificial impact and understanding the acoustic radiation characteristics of the floor.

3.1 Preliminary Sound Quality Issues

Before the testing of flooring samples and sound jury could begin, the objective psychoacoustic metrics that should be considered and framework for the sound jury were identified. The objective psychoacoustic metrics and sound jury procedures are presented in this section, so that their specific implementation in the experimental method can then be discussed in Chapter 4.

3.1.1 Relevant Psychoacoustic Metrics

The purpose of this section is to introduce psychoacoustic measures which are used to characterize the human perception of sound. The metrics objective **Loudness**, objective **Sharpness**, objective **Roughness**, and objective **Fluctuation Strength** were pioneered by Eberhard Zwicker and Hugo Fastl. The Zwicker and Fastl metrics are widely employed in long duration signals, such as engine noise. The metrics **Subjective Duration**, **Perceived Pitch**, and the **Spectral Flatness Measure** may be important in short duration impulse signals. Their relevance to impulse sound is discussed in the following sections.

3.1.1.1 *Objective Loudness*

Objective **Loudness** is an objective measure of sound intensity, which incorporates both the spectral components of the signal and the temporal pattern of the auditory system. Objective **Loudness** better describes the human perception of sound intensity than other weighting curves, such as the A-weighting curve. The unit of objective **Loudness** is the "sone". Objective **Loudness** linearizes the "phon" scale, which is the unit of measure for the A-weighting curve. Therefore, a 10 dB increase in sound pressure level corresponds to a doubling of the objective **Loudness**. The frequency content is modified to mimic the shape of the human auditory filter by using the Bark scale [16]. The basic calculation for objective **Loudness** is provided by

$$N = \int_{0}^{24\,Bark} N' dz$$

where *N'* is each value of **Specific Loudness** and *z* is the critical band rate. [8].

3.1.1.2 *Objective Sharpness*

Objective **Sharpness** is an objective measure predominantly related to the envelope of the acoustic signal's spectrum, the spectral content, and the center frequency (if the signal is narrow-band). Objective **Sharpness** is a relative measure, with the reference signal of a narrow band noise centered at 1 kHz and with a sound pressure level of 60 dB. The unit of objective **Sharpness** is the "acum". The fine structure of the signal's spectrum is unimportant to the perception of objective **Sharpness**, due to the influence of the critical bands of the human auditory system. The human auditory system essentially integrates the spectrum across each critical band [16]. The equation for the objective **Sharpness** metric is given by

$$S = c \cdot \frac{\int_0^{24} N' g'(z) \cdot z \cdot dz}{\int_0^{24} N' \cdot dz}$$

where *N'* is the **Specific Loudness**, *g'(z)* is a weighting function, *z* is each of the critical bands, and *dz* is the critical band rate and is approximated by 0.1 Bark [8]. The weighting function is

$$\begin{aligned} &z < 14 \Rightarrow g'(z) = 1 \\ &z \geq 14 \Rightarrow g'(z) = 0.00012z^4 - 0.0056z^3 + 0.1z^2 - 0.81z + 3.51 \end{aligned}$$

3.1.1.3 *Objective Roughness*

Objective **Roughness** is an objective measure of the modulation of a signal. It is specifically used for noise with modulation frequencies between 15 Hz and 300 Hz, where the objective **Roughness** of a signal is most heavily perceived. The objective **Roughness** of a signal is dependent upon the modulation frequency, and the magnitude of modulation. The magnitude is the degree of modulation for amplitude modulation amplitude and the frequency modulation index for frequency modulation. The unit of objective **Roughness**, the "asper", is defined as a 1 kHz tone at 60 dB that is 100% modulated in amplitude with a modulation frequency of 70 Hz [16]. The model for objective **Roughness** used in this thesis is calculated by

$$R = cal \times \int_0^{24} f_{\mathrm{mod}} \cdot \Delta L \cdot dz$$

where *cal* is the calibration factor, f_{mod} is the frequency of modulation, ΔL is the perceived masking depth, and dz is the critical band rate. ΔL is difficult to quantify, and there is currently no standardized metric. For broadband signals similar to the impact sounds creating with flooring impacts, the objective **Roughness** model developed by Daniel and Weber (1997) helps to adjust the model to improve the results for broadband noise [17].

3.1.1.4 *Objective Fluctuation Strength*

Objective **Fluctuation Strength** is an objective measure of modulation, similar to that of objective **Roughness**. However, objective **Fluctuation Strength** better describes the perception of the modulation when the modulation frequency is at or below 20 Hz. The human perception of objective **Fluctuation Strength** is strongest at 4 Hz. The unit of objective **Fluctuation Strength** is the "vacil" and is defined a 1 kHz tone at 60 dB that is 100% modulated in amplitude with a modulation frequency of 4 Hz [16]. Objective **Fluctuation Strength** is calculated by

$$F = \frac{0.008 \times \int_{0}^{24} \Delta L \cdot dz}{\left(f_{\mathrm{mod}} / 4Hz \right) + \left(4Hz / f_{\mathrm{mod}} \right)}$$

where ΔL is the perceived masking depth, f_{mod} is the frequency of modulation, and dz is the critical band rate [8].

3.1.1.5 *Objective Subjective Duration*

Objective **Subjective Duration** is the measure of the perceived duration of signals. In long signals, there is no difference in the objective **Subjective Duration** of a signal and the actual duration of a signal. However, in samples with a very short length, the objective **Subjective Duration** may be longer than the actual duration. This phenomenon is shown to be detectable in a 1 kHz tone shorter than 100 ms and is shown in Figure 10. The unit of objective **Subjective Duration**, the “dura”, is defined as the objective **Subjective Duration** of a 1 kHz tone at 60 dB broadcast for 1 second [16].

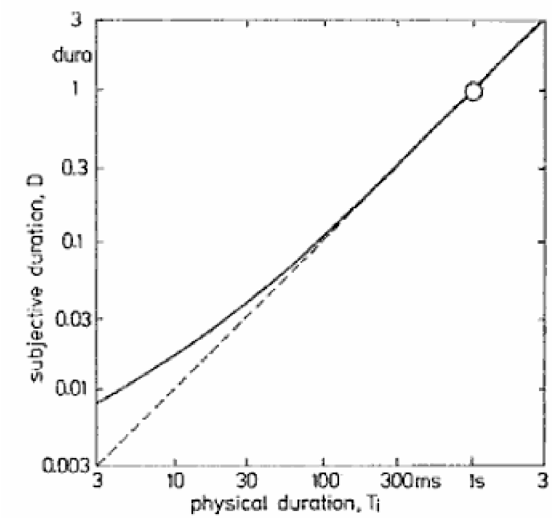

Figure 10: Objective **Subjective Duration** of a 1 kHz, 60 dB tone (in “dura”) versus its physical duration (in time) [16].

3.1.1.6 *Objective Perceived Pitch*

The objective **Perceived Pitch** of a complex signal may be characterized by one of two predominant theories of how the brain resolves the harmonic components of a sound. The spectral theory essentially converts a sound into its individual frequency components. Next, the frequency components are analyzed to find the harmonic series that best match the individual frequency components [18]. The temporal theory describes the perception of pitch as the time pattern or the waveform, as it is formed on the basilar membrane. The pitch is related to the time interval between neural firings that result from the membrane’s displacement [18].

Signal processing techniques designed to estimate the objective **Perceived Pitch** of a complex signal often use local minimums and maximums of the signal's spectrum to select the dominant harmonic components. Analysis of the frequency and amplitude of the dominant components is then used to estimate the pitch. For impulse signals, the pitch can be estimated through the tonality, which is proportional to the **Spectral Flatness Measure** [10].

3.1.1.7 *Objective Spectral Flatness Measure*

For short duration sounds, the objective **Perceived Pitch** of the sound event may be best taken as a single dominant pitch. Estimating the tonality of harmonic complexes, or broadband sounds, can be used to evaluate the sound's objective **Perceived Pitch** [19]. The **Spectral Flatness Measure** may be used to quantify the tonality coefficient and resulting tonal quality of the signal [10]. The **Spectral Flatness Measure** is calculated by

$$SFM = \frac{\sqrt[N]{\prod_{n=0}^{N-1} x(n)}}{\sum_{n=0}^{N-1} x(n) \Big/ N}$$

where N is the total number of samples and $x(n)$ is the magnitude of the acoustic pressure across the frequency spectrum [20]. Most simply stated, the **Spectral Flatness Measure** is the geometric mean of the acoustic pressure in the frequency domain divided by the arithmetic mean of the acoustic pressure in the frequency domain.

3.1.2 Sound Jury Procedures

The purpose of this section is to present the primary factors that must be considered with developing a sound jury procedure. In order to obtain good results from a sound jury, proper techniques must be followed, because results of sound jury evaluations are highly sensitive to the way they are administered [4].

3.1.2.1 *Sound Samples Preparation*

Sound samples presented to sound jury subjects should be free from all extraneous sounds, which are not part of the signal which is to be evaluated. All contaminated segments of a recording must be removed or a different sound sample should be used. Sound samples should be at least 3 to 5 seconds in length. If a transient, short duration sound sample is to be evaluated, multiple playbacks of the sound sample may be used to aid in perception [21].

3.1.2.2 *Sound Jury Room*

Sound jury studies may be conducted with a live action presentation of a test, or as a recorded test. In a live action test, sound samples are created in real-time, whereas in a recorded test, sound samples have been pre-recorded. A live action test is the most realistic way to present the juror with sound samples that they are asked to evaluate, but it is also the most difficult to control. The repeatability of a live action test is difficult to replicate. For this reason, presenting sound samples from recordings results in the exact same experience from juror to juror.

Recorded sound samples may be presented over loudspeakers or headphones. Loudspeaker playback can be problematic, due to the effects of the listening room on the integrity of the original signal. For sound jury testing evaluations using headphones, many room acoustics issues may be ignored. However, several concerns must be addressed. First, a high level of noise isolation must be present, so that the subject will not have difficulty listening to the recorded sound samples over background noise. The volume of the sound samples should be presented at a comfortable volume, so that jurors are not fatigued by loud noises, nor is their hearing jeopardized. Also, subject comfort must be maximized, so that anxiety levels are reduced. The listening environment should be as natural as possible. Lighting should be adequate enough to allow the subject to comfortably perform the tasks. Thermal climate in the room should also be comfortable. A visual representation of the recording will help a subject visualize the intent of the test [21].

3.1.2.3 *Session Length*

The overall length of the sound jury experiment should be no longer than 30 to 45 minutes. Increasing session length beyond this duration greatly increases the influence of juror fatigue. The number of samples that can be presented to jurors for evaluation should be estimated based on the governing time limit [21].

A sound jury session consists of a number of parts, including reading and signing consent forms, taking an audiogram, experimental protocol training, and finally the sound jury experiment. The time to complete each part should be estimated to determine the total amount of workload that can be given to the juror in the actual sound jury experiment.

3.1.2.4 *Juror Training*

Before a juror begins the experiment, a training session should be performed to familiarize the juror with the task to be completed. Subjects should be presented with training sounds that show the magnitude of the differences between the sound samples presented in the study. Furthermore, the training sessions should include examples of how to complete the evaluation task, so that the subject is comfortable with the experiment [21].

3.1.2.5 *Jury Evaluation Methods*

There are several jury evaluation methods which may be used in a psychoacoustics experiment. The driving factor for selecting the type of experiment which will provide the desired results is the number of samples to be evaluated. Two common methods used to evaluate jury perceptions are semantic differential and paired comparison. The juror should be provided with bipolar adjective pairs when evaluating sounds in both of these protocols. Bipolar adjective pairs are antonyms of each other, which qualify the type of characteristic the subject is to evaluate in layman's terms. When choosing bipolar adjective pairs, it is important to select adjective descriptors which are easy for all subjects to understand. Technical terms should be avoided [21]. The details for both the semantic differential and paired comparison protocols are presented below.

Semantic Differential

In a semantic differential experiment, a juror is provided with a single sound sample for evaluation. If n sound samples are to be evaluated, n individual tests will be required to evaluate the complete data set. The juror then rates their perception of the sound sample based on a how they perceive the sound sample performs relative to a bipolar adjective pair. The juror may rate both the attributes (loud/quiet) and their impressions (good/bad) of the sound [21]. For large data sets, semantic differential is widely used and provides good results.

Paired Comparison

In a paired comparison experiment, a juror is provided with two sound samples for evaluation. The subject is asked to rate how similar/dissimilar one sound sample is relative to another. The juror may rate both the attributes (loud/quiet) and their impressions (good/bad) of the sound samples [21]. A typical paired comparison experiment will ask the subject to rate the perceived similarity between every possible combination of sound sample pairs. If *n* sound samples are to be evaluated, *n(n-1)* individual tests will be required to evaluate the complete data set.

3.1.3 Sound Quality Index Procedures

In this section, the process used to evaluate the sound quality of a product by creating a sound quality index is discussed. Each step used to create a sound quality index is presented below.

Commonly, a sound quality index is used to factor in all relevant objectivemeasures into a single number output, which describes the overall sound quality of a signal. The sound quality index removes statistically insignificant sound quality metrics and then applies weighting curves to all remaining terms based on their correlation coefficients. The resultant sound quality index is then an objective representation of the overall sound quality of a signal [8].

3.1.3.1 *Normalize Data*

Jurors will use the same scale during the sound jury differently. Jurors may tend to rate their perceptions using wide jumps in the rating scale, while others may rate differences in perception with smaller jumps. Jurors may also rate their subjective perceptions with different average means. To create equal weightings between all jurors, the scores of each juror should be normalized, such that normalized scores for each evaluation category (e.g. subjective *Loudness*, subjective *Pitch*, subjective *Quality*) have a mean of zero and a standard deviation of one [8]. All of the sound jury results were normalized for each juror, using

$$x_{nor} = \frac{x - \overline{x}}{\sigma}$$

where x_{nor} is the normalized data point, x is the original data point, $\overline{x}$ is the sample mean, and σ is the sample standard deviation [8].

3.1.3.2 *Correlation Coefficients*

A correlation between objective psychoacoustic metrics and subjective sound jury results should be calculated to determine any relationships between the two. The Pearson product moment correlation coefficient, or sample correlation coefficient, is calculated for the relationship between each metric. The correlation coefficient is calculated by

$$r = \frac{\sum(x-\overline{x})(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2 \sum(y-\overline{y})^2}}$$

where x and y are the individual data points and $\overline{x}$ and $\overline{y}$ are the sample means. The sample correlation coefficient is an estimate of the correlation between two random variables, X and Y [22]. A correlation of $r=0$ implies that there is no relationship between the two variables, a correlation of $r=1$ is a perfect correlation, and a correlation of $r=-1$ is a perfect negative correlation. A perfect correlation is exceedingly rare. The significance of a correlation is evaluated in whether or not the correlation is greater than the critical correlation coefficient, which is presented in Section 3.1.3.3 [22].

3.1.3.3 *Critical Correlation Coefficient Level*

A critical correlation level should be established based on the number of degrees of freedom, *df*, and the desired level of statistical significance. All correlations higher than the critical correlation level are regarded as significant relationships. All correlations less than the critical level are discarded, because they are not statistically shown to be more than relationships by chance [8]. The critical correlation level is taken from a table for the Pearson product moment correlation table of critical values.

3.1.3.4 *ANOVA*

An ANOVA experiment, or analysis of variance, should be conducted on the normalized results for all of the subjective metrics. The results of the ANOVA test is used to determine whether or not the results of each metrics are random or not and whether all of the samples tested are the same or different. Establishing whether or not the results of the analysis are significant is done by verifying that the p-value is below 0.05. Determining whether or not the samples are the same is done by comparing the F statistic to the F_{crit} value. An F statistic larger than the F_{crit} value shows that all of the samples tested in the experiment are not all the same sample [8].

3.1.3.5 *Regression Analysis*

A regression analysis should be used to create a model for sound quality metrics with correlation coefficients higher than the critical level, which signifies relationships that are statistically significant. A regression analysis is used to form a model of an output that depends on multiple inputs to describe the behavior [22]. The weighting factor, β_k, for each input is created to minimize the error by method of least squares. The linear regression model takes the form

$$y_i = \beta_0 + \beta_1 x_{1i} + \ldots.. + \beta_k x_{ki} + \varepsilon_i$$

Where y_i is the output, x_{ki} are the inputs, β_k are unknown parameters, and ε_i is the error term [22].

3.1.3.6 *Factor Analysis*

In addition to a regression analysis, a factor analysis may be used to determine primary relationships between variables. Factor analysis "takes thousands and potentially millions of measurements and qualitative observations and resolves them into distinct patterns of occurrence" [23].

3.1.3.7 *Post Hoc t-test*

An ANOVA is used to determine whether or not all of the samples in an experiment are the same. An ANOVA does not determine whether individual samples are significantly different from one another. In order to establish sample-to-sample relationships, a post hoc t-test may be performed on each sample combination. A t-test can be used to determine whether or not the difference between two sample means is significant, based on the mean and variance of each sample [22].

3.2 Preliminary Floor Exploration

Section 3.2 presents two preliminary studies that were investigated as a result of the literature review findings. In the literature review, several impact method types were used to create footfall impact sounds, each with drawbacks. An acceptable impact method was resolved. Also, the potential radiation patterns that may exist in the sound field were investigated, so that an acceptable microphone position could be specified.

3.2.1 Floor Impact Method

A highly repeatable method must be used to create a foot strike floor impact for laboratory testing purposes. The goal was to have an impact method that was easily implemented in both the same and different labs with results that are consistent. Because of the background noise issues discussed in the literature review, the impact machine was determined to be unsuitable for repeated lab testing. Similarly, the inherent variability of using actual human walking creates an insurmountable impediment to laboratory testing.

A ball drop impact method was chosen for its repeatability and lack of machine generated noise. As shown in Figure 11, a ball dropped from a specified height may be used to excite the floor in a highly repeatable manner as long as the drop height and the properties of the ball are controlled.

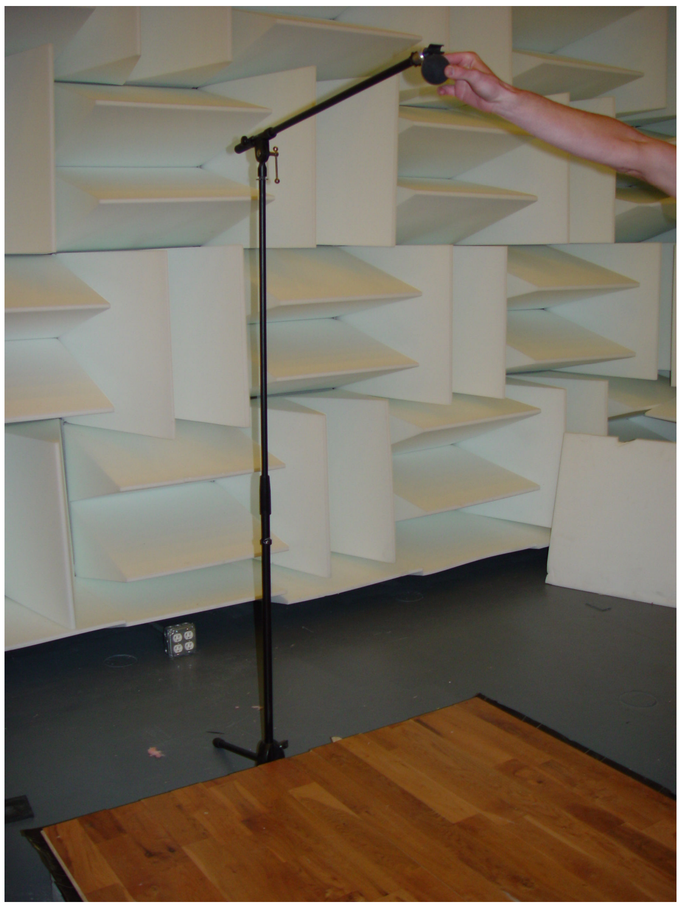

Figure 11: Ball drop test from fixed height (5 ft above floor) and an impact ball with known size and hardness (2" diameter, 95 Shore A).

To recreate a reasonable representation of a footfall with a ball drop, the ball drop height and ball type must be selected, addressing the issue above. The ball drop height was selected so that the ball impact generates a sound level comparable to a footfall. The ball must be selected to generate a spectrum comparable to that of a human footfall. The spectrum generated will be a function of the ball hardness and size, both of which influence the ball's force input upon impact.

A variety of balls were tested for their ability to recreate a footfall-type spectrum. The balls were of different hardness and of different sizes. The hardness of each of the balls was verified against the hardness of the hard rubber heel of male and female dress shoes. The hardness of several male and female dress shoes was measured with a Shore hardness durometer. A ball that best represented the acoustics of the dress shoes was selected as the impact ball.

A schematic of the ball drop setup is shown in Figure 12. The selected ball was an ASTM certified nylon 2" diameter test ball with a density of 70 lb/ft^3 and a hardness of 95 Shore A [24]. The ball was dropped from a height of 5' above the test floor. A ball drop marker was centered over the test sample, so that the ball impacts the floor at the same position and from the same height for each sample. The stand for the ball marker was not placed on the test article surface, so that the vibration characteristics of the floor were not influenced.

Additionally, the floor was tested in an unloaded state. Loading of the floor is used in floor impact testing, such as ISO 140.8 [6]. However, because the vibration characteristics of the floor dictate the spectral content of the impact, no loading was used in this testing. Any attempt to load the floor would require extremely close tolerances on load placement to prevent load placement error from substantially contributing to repeatability error. For all recordings in the psychoacoustic study, the microphone was positioned 45 degrees off axis, 48” away from the impact zone in both the x and y directions, as shown in Figure 12. The elevation of the microphone was 60” above the floor of the hemi-anechoic chamber. This microphone position was derived from the study on the radiation characteristics of the floor, which is presented in Section 3.2.

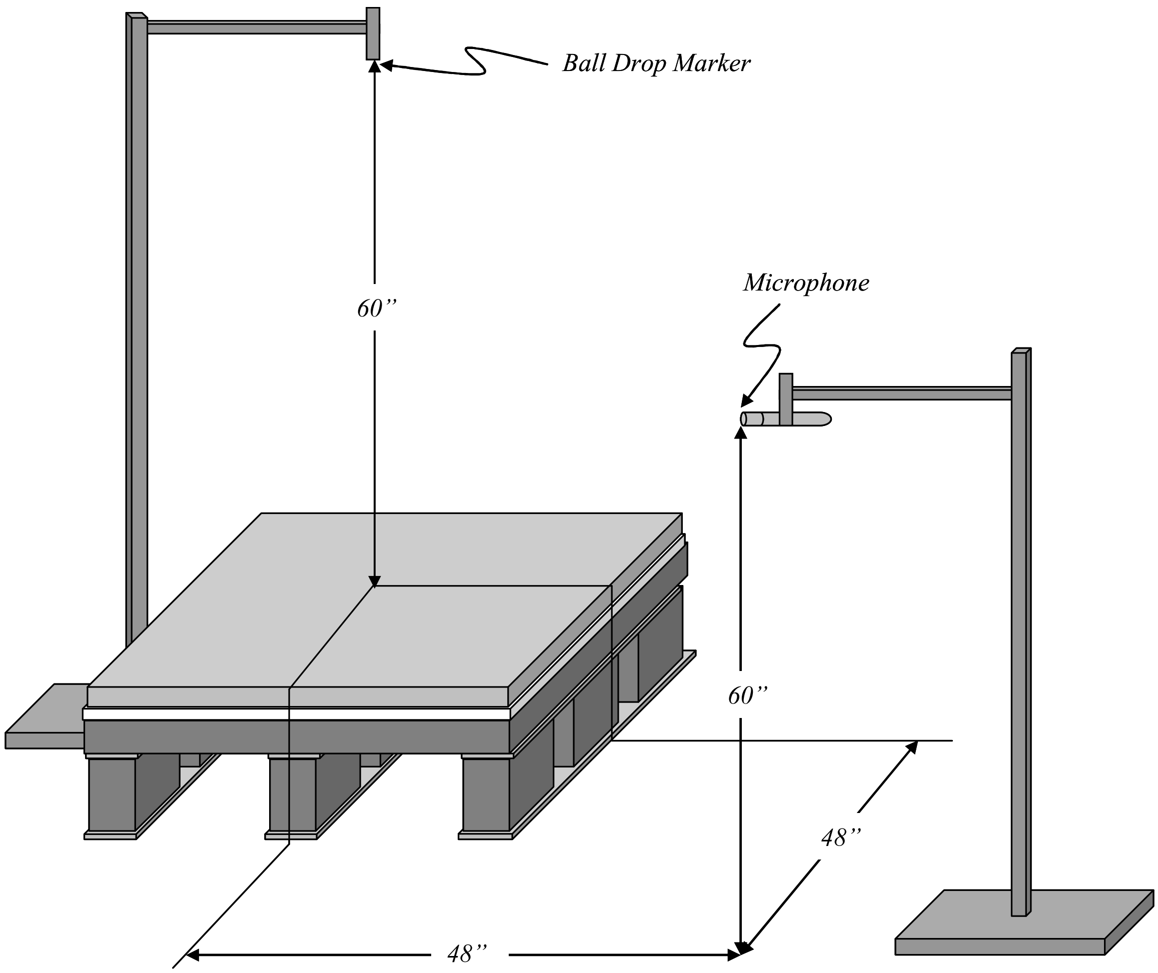

Figure 12: Schematic of the ball drop setup.

The repeatability of the ball drop was investigated by calculating the descriptive statistics for all psychoacoustic metrics that were used in the actual sound jury study. The metrics are discussed in Section 3.1.1. Figures of each metric and their 95% confidence interval are presented in Appendix I. A summary table of the repeatability performance is given below in Table 2. The p-value for each measurement shows that the significance of each measurement is statistically significant to a 95% level of confidence. The F statistic represents the ratio of the variation between samples to the variation within the samples. A higher F statistic represents a more capable measurement. All of the F statistic values are well above the Fcrit value of 1.63 (95% level) and 1.98 (99% level) for this particular measurement. Therefore, all of the calculated psychoacoustic metrics used in the study are capable when created by a ball drop test with 5 replicates of each impact.

Table 2: ANOVA results for each calculated psychoacoustic metric used in the study.

Calculated Psychoacoustic Metrics	p-value	F statistic	F crit (95%)
Loudness	< 0.01	24.86	1.63
Sharpness	< 0.01	22.77	1.63
SFM	< 0.01	20.23	1.63
Fluctuation Strength	< 0.01	46.40	1.63
Roughness	< 0.01	13.89	1.63

3.2.2 Floor Radiation Characteristics

In order to better understand how a laminate flooring composite responds to an impact, initial testing was performed on the bare concrete floor of the hemi-anechoic chamber. The bare concrete floor of the hemi-anechoic chamber was an ideal place to study the vibration of the flooring composite due to the extremely low damping of the concrete slab. Initial tests were performed on laminate flooring composites as well as engineered flooring composites.

The radiation pattern of the floor was tested by performing drop tests on flooring composites with an array of microphones. Figure 13 shows a schematic of the floor sample and the microphone array. The array was used to take measurements of a ball drop at a distance of 30" and 60" from the impact and at radial positions of 0º, 45º, and 90º.

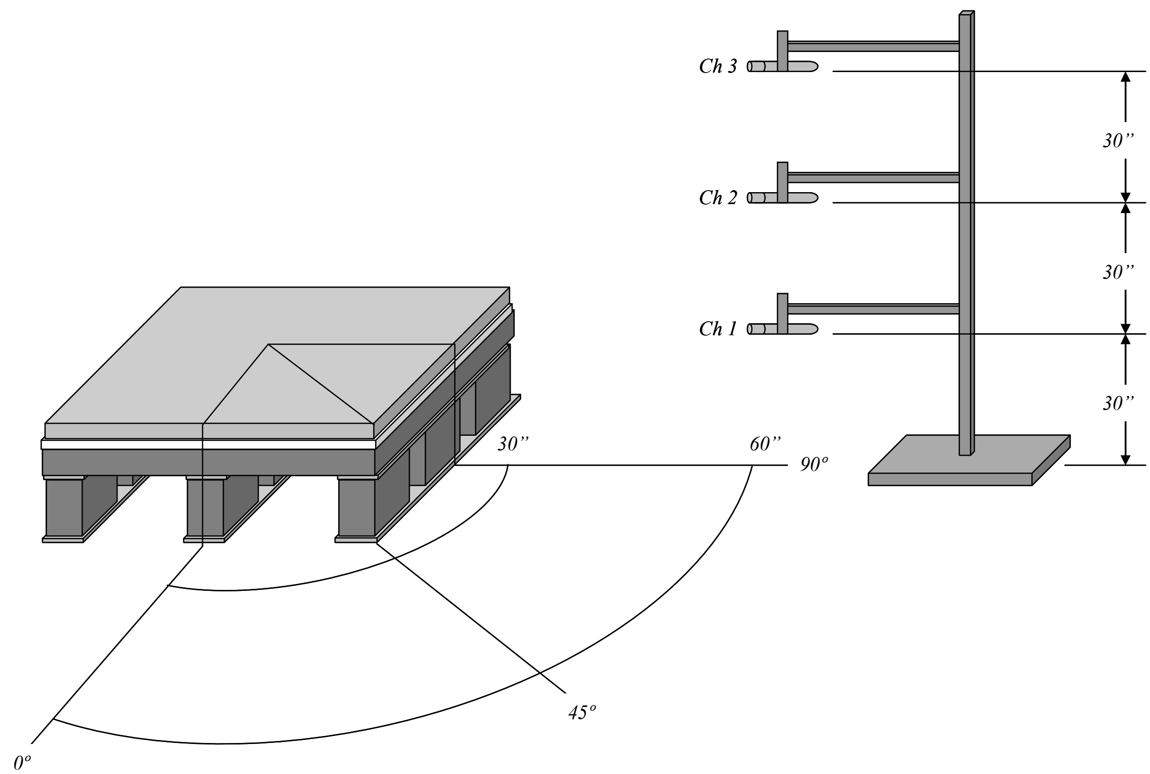

Figure 13: Flooring sample with 3-microphone array for radiation pattern testing.

The spectral content for each microphone position is provided in Figure 14. Inspection of each plot showed that the sound field created by the impact is non-uniform. The measured frequency response of the floor changed significantly at each measurement point as the microphone is moved in 3D space. Consequently, microphone placement must be clearly specified and adhered to when performing all tests. Specifically, microphones should not be placed directly over the impact zone and should be placed somewhere off of the flooring sample to help minimize the probability of the microphone location being in a dominant mode's null. Furthermore, the presence of a non-uniform sound field showed that experimental measurements will not be repeatable if the microphone is moved from one experiment to another. The microphone position used in the study is shown in Figure 12: Schematic of the ball drop setup.Figure 12 presented in Section 4.1.2.

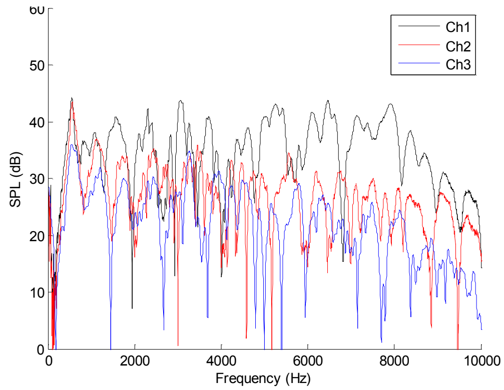

Figure 14 (a): Angle - 90º, Distance - 30”

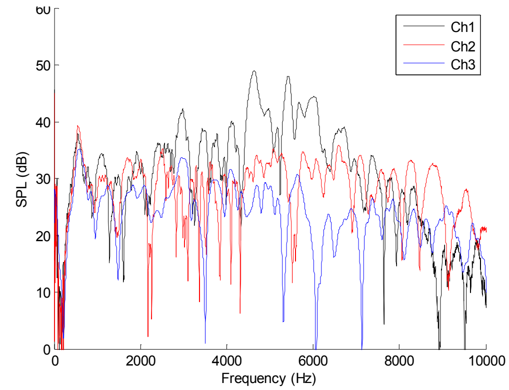

Figure 14 (b): Angle - 90º, Distance - 60”

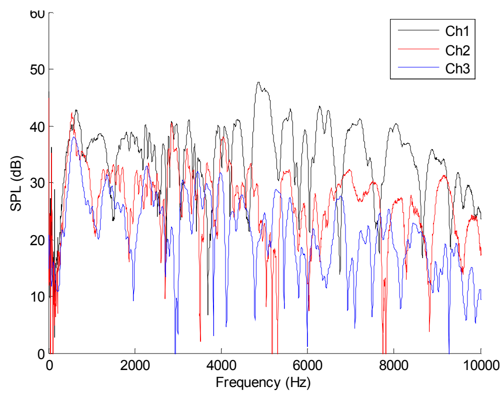

Figure 14 (c): Angle - 45º, Distance - 60”

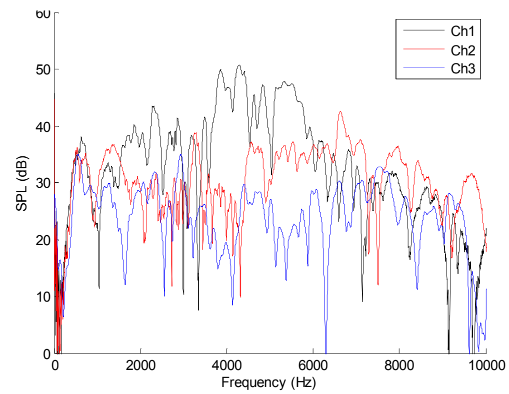

Figure 14 (d): Angle - 45º, Distance - 30”

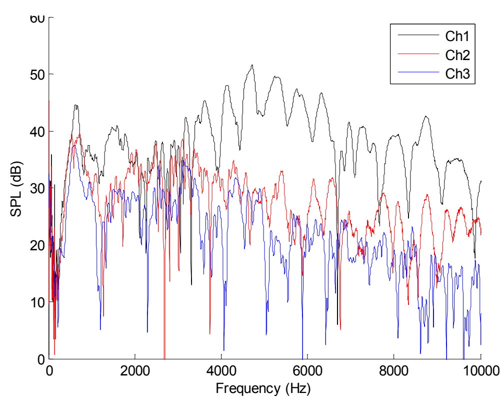

Figure 14 (e): Angle - 0º, Distance - 30”

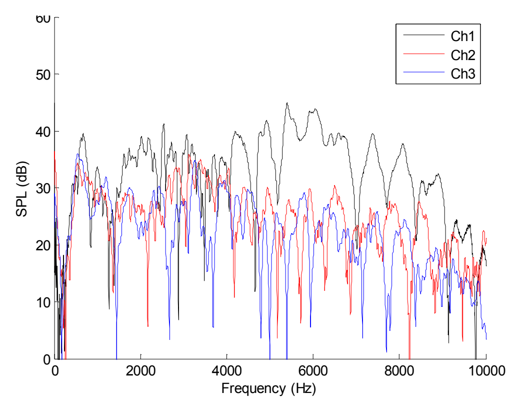

Figure 14 (f): Angle - 0º, Distance – 30”

Figure 14: Spectral content of each position of the 3-microphone array depicted in Figure 13.

CHAPTER 4. EXPERIMENTAL METHOD

The purpose of this chapter is to present the method used in the laboratory tests and sound jury study. Both the laboratory test method and sound jury method were created based on the findings of the procedure development chapter. Details from two sound jury studies are discussed in this chapter. The first study is referred to as the semantic differential study, and the second study is referred to as the paired comparison study. The paired comparison study was initiated based on the results of the semantic differential study. The reasons for the paired comparison study are provided in Section 5.1.1.6.

4.1 Laboratory Test Method

Section 4.1 provides the detailed procedure used for constructing flooring sample test articles, the method used for impacting the test articles, and the method used to record the sound samples for analysis.

4.1.1 Flooring Composite Assemblies

Several different types of flooring composites were constructed for testing. The flooring tested in the study consists of a variety of composites. A test sample is comprised of a subfloor, an underlayment, a flooring, and an installation attachment method. All of the samples are 4’ x 4’ in size.

A concrete subfloor and a wood frame subfloor were constructed to serve as the subfloor assemblies. The concrete subfloor was used to test the engineered hardwood flooring and laminate flooring with each underlayment in a floating installation as well as a floating hardwood sample. A glue-down hardwood sample was also installed on a concrete subfloor sample. A wood frame subfloor was used to test hardwood flooring in a floating installation. Figure 15 shows the three different types of installations that were used in all of the testing and the samples that were created from each assembly type. The details of how each component was constructed are provided in Section 4.1.1.1 through Section 4.1.1.3.

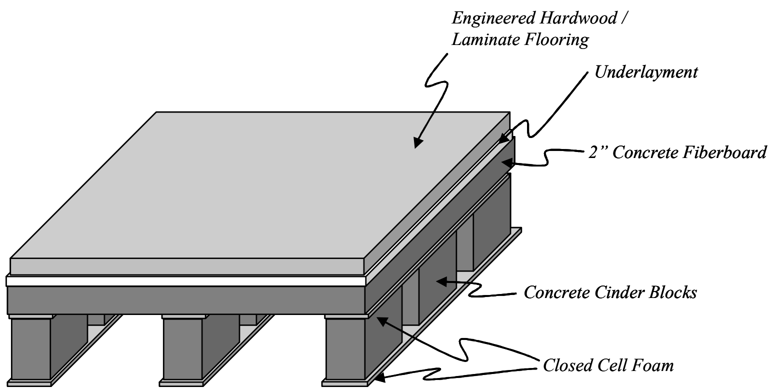

Figure 15 (a): Laminate and engineered hardwood flooring / underlayment / concrete subfloor / floating installation (Sample 1-22).

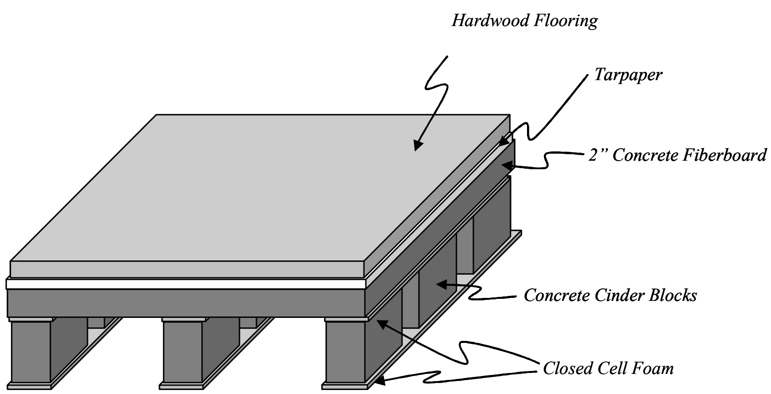

Figure 15 (b): Hardwood flooring / tarpaper / concrete subfloor / floating installation (Sample 23) and glue-down installation (Sample 25).

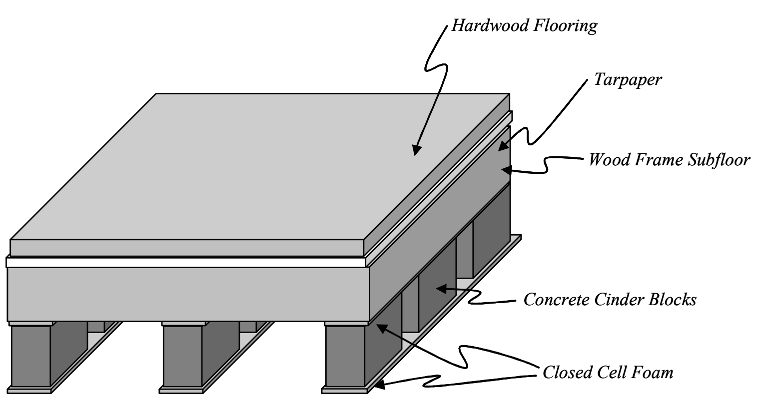

Figure 15 (c): Hardwood flooring / tarpaper / wood frame subfloor / floating installation (Sample 24).

Figure 15: Flooring composite sample assemblies.

The complete list of samples constructed and tested is given in Table 3. Samples 1-24 were tested in both the semantic differential study and the paired comparison study. Sample 25 was only evaluated in the paired comparison study. The underlayment materials used in the study were provided for testing by the sponsoring company. A general description of the underlayments is provided in Table 3.

Table 3: Flooring composite sample list used in sound jury testing.

Sample	Subfloor	Underlay	Flooring	Installation	Underlay Description
1	Concrete	1 4	Laminate	Floating	
2	Concrete	1 4	Engineered	Floating	lightweight large closed cell foam
3	Concrete	1 7	Laminate	Floating	
4	Concrete	1 7	Engineered	Floating	lightweight large closed cell foam
5	Concrete	2 3	Laminate	Floating	
6	Concrete	2 3	Engineered	Floating	lightweight small closed cell foam
7	Concrete	2 4	Laminate	Floating	
8	Concrete	2 4	Engineered	Floating	cork
9	Concrete	2 10	Engineered	Floating	
10	Concrete	2 10	Laminate	Floating	fine closed cell foam w/ film
11	Concrete	3 7	Laminate	Floating	
12	Concrete	3 7	Engineered	Floating	thin light closed cell foam
13	Concrete	3 8	Laminate	Floating	
14	Concrete	3 8	Engineered	Floating	light closed cell foam
15	Concrete	3 9	Laminate	Floating	
16	Concrete	3 9	Engineered	Floating	dense closed cell foam w/ film
17	Concrete	4 7	Laminate	Floating	
18	Concrete	4 7	Engineered	Floating	dense rubber w/ fabric scrim & film
19	Concrete	4 10	Laminate	Floating	
20	Concrete	4 10	Engineered	Floating	dense open cell foam w/ fabric scrim & film
21	Concrete	4 18	Laminate	Floating	
22	Concrete	4 18	Engineered	Floating	dense foam w/ 2 sides film
23	Concrete	tar paper	Hardwood	Floating	standard roofing tap paper /
24	Wood	tar paper	Hardwood	Floating	red oak prefinished hardwood
25	Concrete	tar paper	Hardwood	Gluedown	glue down same as above otherwise

4.1.1.1 *Flooring Types*

There were three different types of floors used in the study: traditional hardwood floors, engineered hardwood laminate floors, and laminate floors. The traditional hardwood floor was utilized as a reference against which all of the laminate type composites were compared. The following section provides the method of construction and installation of each flooring type.

In this study, the hardwood flooring planks were 5/8" thickness red oak with a prefinished stain and varnish surface. The hardwood flooring was installed with a tarpaper backing, typical of field installations.

The hardwood floors were installed using Liquid Nails construction adhesive [25]. A 4' x 4' layer of tarpaper was laid on the ground. A bead of construction adhesive was applied to the tar paper, as shown in Figure 16. The hardwood planks were glued together with a bead of construction adhesive run along the length of the tongue-and-groove joint, as shown in Figure 17. The hardwood planks were laid on the tarpaper base in the orientation shown in Figure 16, so that the planks are perpendicular to the adhesive on the tarpaper.

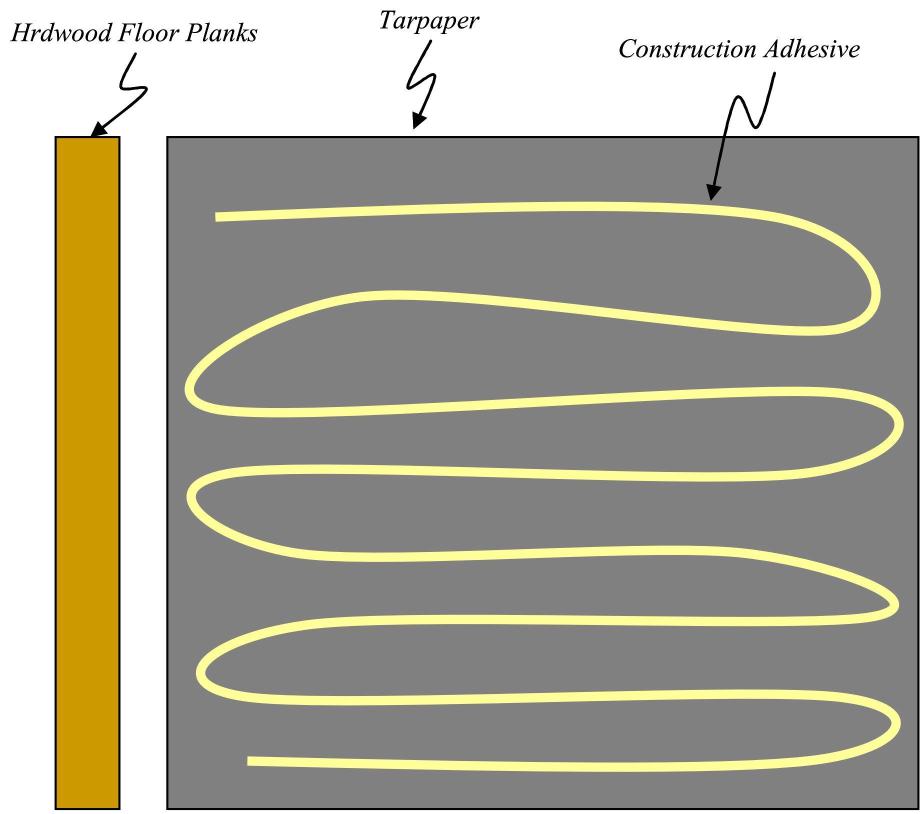

Figure 16: Glue pattern on tarpaper with hardwood floor plank orientation used in hardwood test articles.

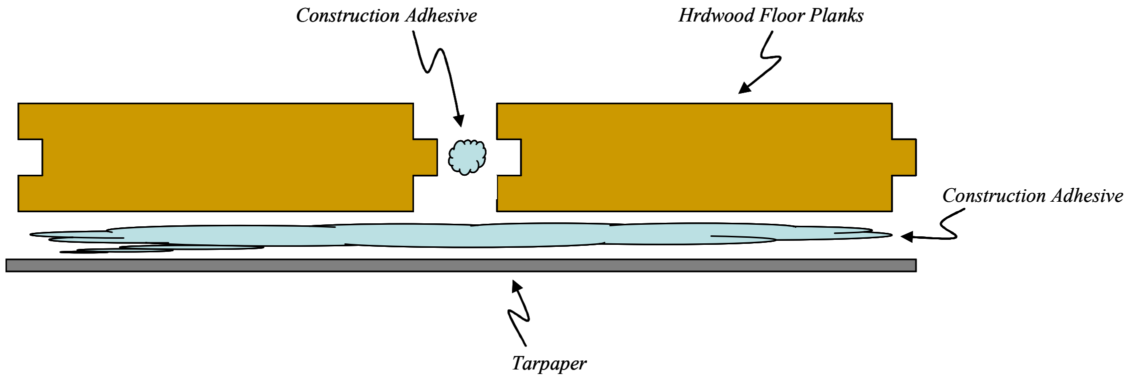

Figure 17: Adhesive points between planks and on the tarpaper in construction of the hardwood test articles.

The hardwood flooring was installed for testing in three different ways. The hardwood floor was installed in a free floating installation on top of a concrete subfloor as well as a wood frame subfloor, both of which are presented in Section 4.1.1.3. The hardwood flooring was laid in a floating installation with no attachment mechanism to the subfloor composites. Samples 23 (concrete subfloor) and 24 (wood frame subfloor) were the two floating installations. In the glue-down installation on a concrete subfloor, the hardwood and tarpaper assembly depicted in Figure 18 were glued to the concrete subfloor.

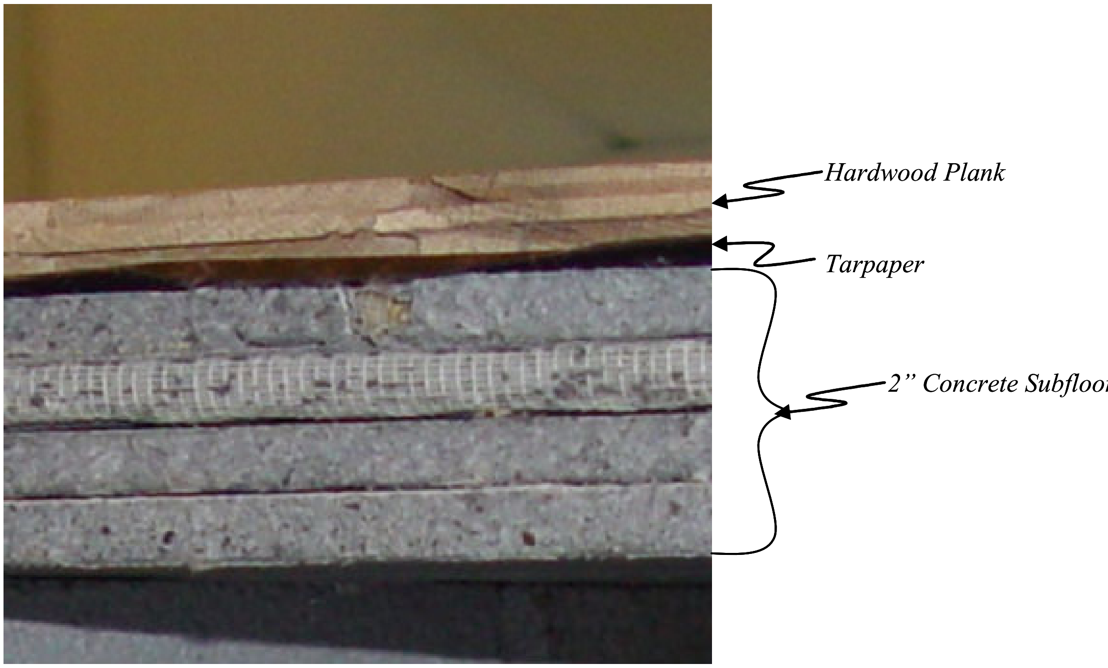

Figure 18: Experimental setup for hardwood flooring on concrete installation.

The engineered hardwood flooring planks used in this study consisted of a thin red oak layer on top of plywood. The engineered hardwood was prefinished and varnished. The thickness of the planks was 15mm. The engineered hardwood planks used in the study were click-lock type planks. The engineered hardwood laminate floors samples were all floating floor installations on the concrete subfloor. The underlayment to be tested was laid on top of the concrete subfloor in a floating installation. The engineered hardwood laminate was installed in a floating installation on top of the underlayment, as shown in Figure 19.

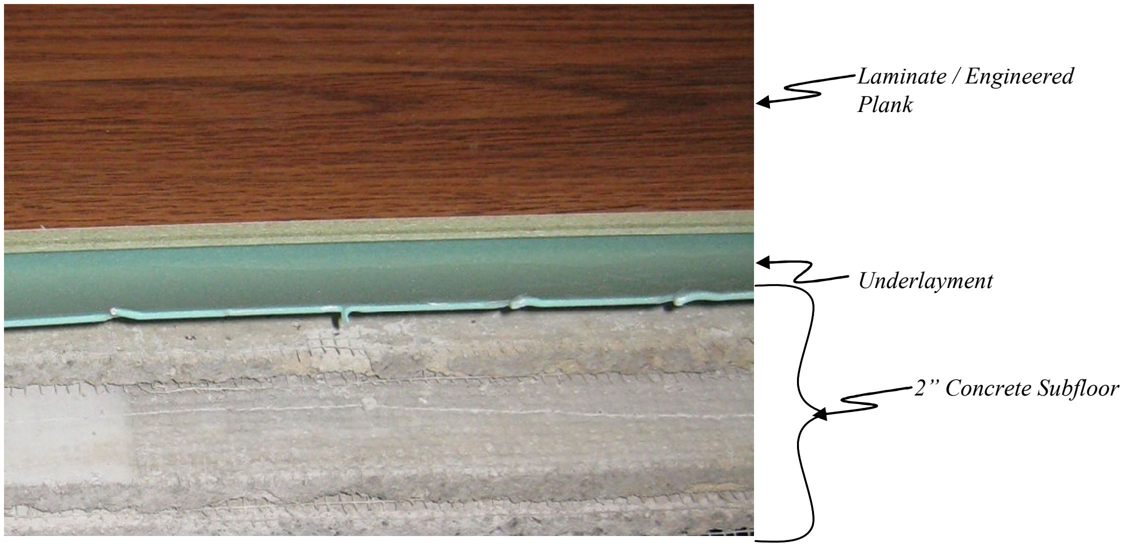

Figure 19: Experimental setup for floating laminate/engineered flooring installed with underlayment on concrete.

In this study, 12mm thick laminate planks were used. It was a typical glueless interlocking plank with the construction details as introduced previously in Section 1.1.1.1: a melamine wear layer, a print layer, a fiberboard core, and a melamine backing [26]. The laminate planks used in the study were click-lock type planks. The laminate floors samples were all floating floor installations on the concrete subfloor, as shown in Figure 19. The underlayment to be tested was laid on top of the concrete subfloor in a floating installation. The laminate was installed in a floating installation on top of the underlayment.

4.1.1.2 *Underlayment Types*

All of the underlayments evaluated in the study were installed in a floating installation, as shown in Figure 19. Each underlayment was tested with both the engineered hardwood laminate and the standard laminate floors.

4.1.1.3 *Subfloor Types*

Two different types of subfloor were used in the experiments: concrete and wood frame. The concrete subfloor comprises multiple layers of concrete fiberboard designed to mimic the installation of a floor on a concrete slab. The wood frame subfloor was used to mimic the installation on traditional wood frame construction. Both assemblies were built into a 4' x 4' size. In addition to their common size, both subfloors were placed on identical concrete masonry unit (CMU) supports [27].

The concrete fiberboard subfloor was constructed of 4 plies of ½" concrete backer board [28]. The fiberboard was cut from 5'x 3' sheets into 4' x 3' size and 1' x 4' size. The sheets were then glued together using Liquid Nails Construction Adhesive [25]. To ensure that the same amount of glue was used on each layer, a whole tube was used per layer. Because there was a seam in each layer, the orientation of the concrete backer board was rotated by 90 degrees for each layer, so that the seams did not traverse through the whole thickness of the laminated final product, as shown in Figure 20.

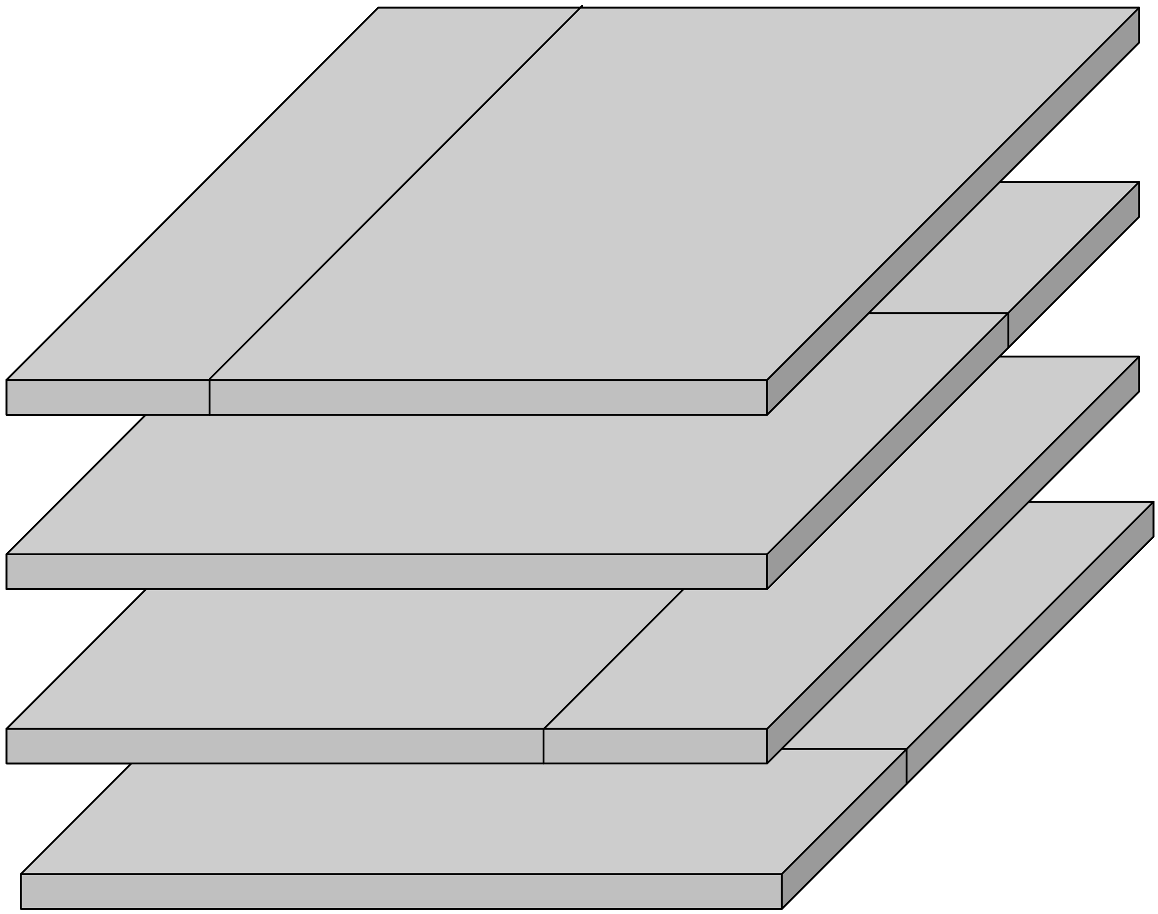

Figure 20: Concrete backer board stacking schematic (each layer rotates 90 degrees) used to create concrete subfloor for testing.

The wood frame subfloor was constructed using 3/8” plywood attached to a 2” x 4” yellow pine frame with standard deck screws, using the assembly schematic shown in Figure 21. Additionally, a bead of Liquid Nails Construction Adhesive was run along the deck frame before the plywood was laid down to prevent potential creaking.

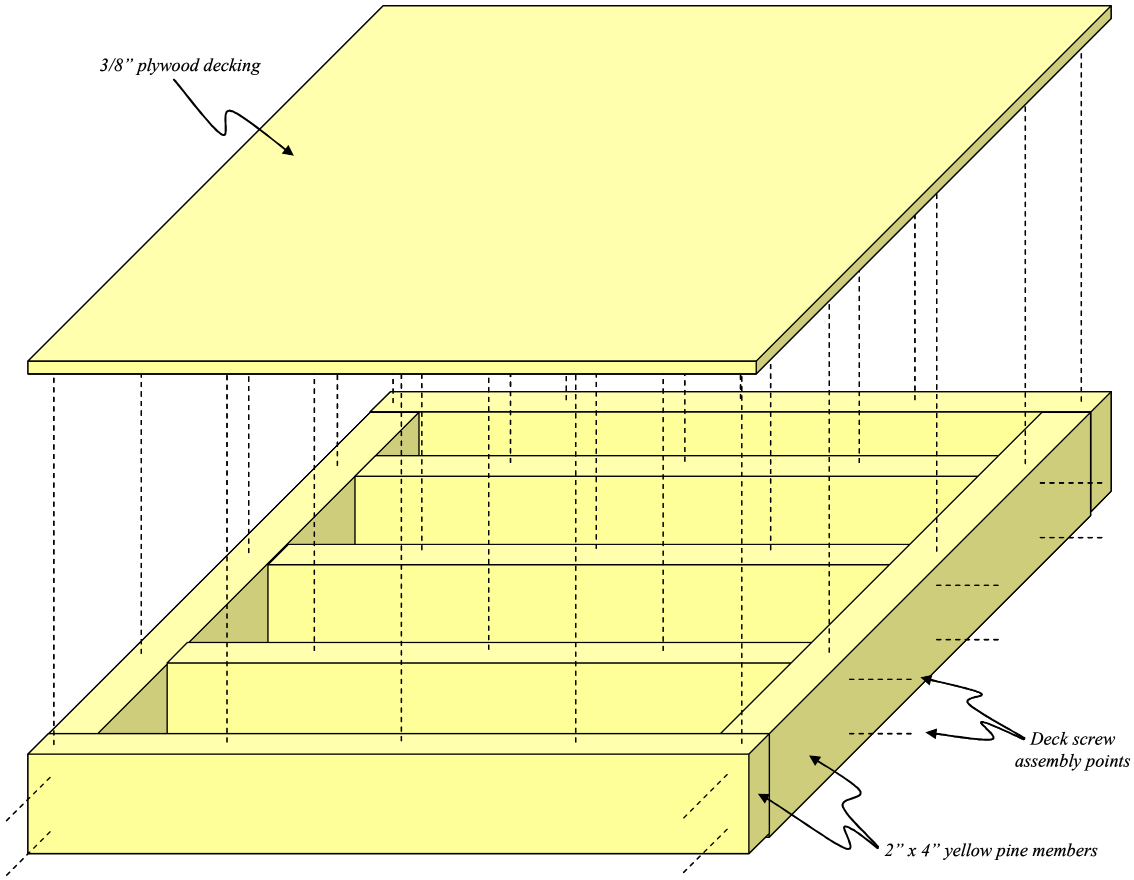

Figure 21: Wood subfloor assembly schematic (dashed lines are screw down points) used to create wood frame subfloor for testing.

4.1.2 Floor Impact Method

The floor impact method was taken from the preliminary impact method study in Section 3.2.1. The ASTM certified nylon 2" diameter test ball with a density of 70 lb/ft^3 and a hardness of 95 Shore A was dropped from a height of 5' above the test floor [24]. A ball drop marker was centered over the test sample for accurate height and position placement. The flooring samples were tested in an unloaded state, and the ball market stand was not placed on the test article surface, so that the vibration characteristics of the floor were not influenced as shown in Figure 12. The microphone was positioned 45 degrees off axis, 48” away from the impact zone in both the x and y directions with an elevation of 60” above the floor as shown in Figure 12.

4.2 Sound Jury Procedures

Section 4.2 details the sound jury procedure used to obtain the subjective performance of the samples tested in the laboratory method presented in Section 0. All of the procedures and documents used as part of the sound jury were approved by the Georgia Tech Institutional Review Board, or IRB. The sound jury packets used by the subjects are provided in Appendix VII. All other documentation approved by the IRB is provided in Appendix VIII.

The sound jury listening tests were performed to provide the human perception of hardwood and laminate floors. The human perception of the flooring composites was found through sound jury experiments, where listeners subjectively rated their perception of the floors based on several evaluation criteria. The results of the sound jury were then correlated to calculated psychoacoustical metrics. Two sound juries were conducted as part of this thesis.

4.2.1 Sound Jury Room

In the first study, performed on the Georgia Tech campus, the hemi-anechoic chamber was used as the venue for the experiment (a quiet office had been sought, but no suitably quiet space was found). The drawback to the chamber was that it is not a natural environment as compared to an office. The temperature in the chamber was comfortable and the lighting level was good. The test was conducted with a laptop set up on a portable table. For the entirety of the experiment, an image of a laminate wood flooring installation was visible on the computer used in the experiment; however, it was not discernable what specific type of flooring composite construction shown in the image.

Figure 22: Sound jury testing in the hemi-anechoic chamber

In the second study, the testing was performed on site at the sponsoring company's facility, so that more females could be recruited for the experiment. To determine the best location at the company's facility, a preliminary visit checked background noise levels in all possible conference rooms available. The room with the lowest background noise level was selected. The test is conducted with a laptop set up on the conference room table. For the entirety of the experiment, an image of a laminate wood flooring installation was visible on the computer used in the experiment.

4.2.2 Test Length

The test length of the sound jury session was dictated by the recommended overall maximum test time of approximately 45 minutes [21]. A preliminary time study of the testing finds the times shown in Table 4 were needed for each step of the testing process.

Based on the estimated times required to read and sign the consent forms, complete the audiogram, and complete the juror training session, it was determined that the maximum number of samples which could be used in the study is approximately 25 to 30.

Table 4: Time study for estimated completion times of sound jury tasks.

Task	Estimated Time (min)
Consent Forms	5
Audiogram	10
Training	10
Experiment	20

In the first study, the preliminary time estimation testing showed that the jurors would be able to evaluate approximately 25 samples within the time limit using the prescribed semantic differential protocol. There were a total of 24 samples to be evaluated by the jury. Therefore, each juror evaluated each sample one time.

In the second study, the protocol was changed to a paired comparison study, in an attempt to improve the precision of the results. The paired comparison task is slightly more intuitive than the semantic differential. As a result, the preliminary time study showed that the juror could evaluate up to 30 samples within the time limit.

4.2.3 Juror Training

Before the juror began the evaluation task, he was trained in evaluation term definitions and procedures, so that the juror was familiarized with the terms and procedures before the start of the actual study. The sound evaluation method training material consists of a detailed description of the task that the juror was asked to complete.

First, the juror was provided with definitions of how he was to interpret the sounds that he heard in the study. The five areas that the jury evaluated each sound in are subjective *Naturalness*, subjective *Quality*, subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. The descriptions of each category are given below, directly from the instructions, provided in Appendix VII.

> Naturalness
>
> For the naturalness category, you are asked to rate the floor for how natural you feel the sound is. Please use your previous experience with hardwood floors as the reference for this category.
>
> Quality Floor
>
> For the quality floor category, you are asked to rate how strongly you feel the quality of the floor is based on how you perceive its sound. Please use your previous experience with hardwood floors as the reference for this category.
>
> Pitch
>
> For the pitch category, you are asked to rate how low or how high the perceived pitch of the floor sample is. In layman's terms, pitch is how you perceive a musical note. Please take this time now to play the training sounds for pitch. You will first hear the low pitch impact three times, followed by the high impact three times. Listen as many times as you feel necessary.
>
> Duration
>
> For the duration category, you are asked to rate how sharp or hollow the perceived duration of the floor sample is. Sharper sounds have little to no perceivable echo, while hollow sounds have a fairly high amount of perceived echo. Please take this time now to play the training sounds for duration. You will first hear the sharp impact three times, followed by the hollow impact three times. Listen as many times as you feel necessary.
>
> Loudness
>
> For the loudness category, you are asked to rate how loud or soft the perceived loudness of the floor sample is. Please take this time now to play the training sounds for loudness. You will first hear the loud impact three times, followed by

> the soft impact three times. Listen as many times as you feel necessary.

Next, the juror was provided with a lay-term example of how to perform the evaluation task. The example provided was for rating the flavor strength of coffee. The purpose of the example was to present the exact format to the juror, as well as demonstrate to him exactly how to provide his answer to the task. There were slight differences in the coffee example between the first and second study. The differences were present to maintain the semantic differential and paired comparison formats, so that the training example was totally analogous for both the first and second study. The example for the first study, in the semantic differential format, is provided below. The full training exercise for both studies is provided in Appendix VII.

> As an example, a study created to determine the perceived strength for a cup of coffee might consist of a descriptive response scale similar to the one below:

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Flavor Strength	Mild	|	|	|	|	|	|	|	Bold

> You, the subject, will test the cup of coffee and then rate your impression of the strength, based on the graduated scale (extremely, very, somewhat, neither, ……). If you feel that the cup of coffee was served to you far too mild cold or far too bold, then the most appropriate response might be "Extremely" Mild or "Extremely" Bold. If the cup was served near your preferred strength, then you might respond with "Neither". If the cup of coffee is a little too mild or a little too bold, then the descriptors "Very" or "Somewhat" may be the appropriate response for you to give in the survey.

The juror was then trained on what types of sounds he should expect. The juror was presented with calibration sound pairs to demonstrate reasonable high/low values.

For these training sounds, a sample was recorded that is not from the jury study and then manually adjusted to cover the range of sounds that the subject evaluated during the actual study. The sound editing software *Audacity* was used to filter some of the lower frequency content and higher frequency content out of the sample sound to create the high and low subjective *Pitch* calibration sounds. Next, the sample was edited to increase and decrease the subjective *Duration* of the sound to create the boomy and sharp subjective *Duration* calibration sounds. Finally, the sample was edited to increase and decrease the SPL of the sound to create the loud and soft subjective *Loudness* calibration sounds [29].

4.2.4 Jury Evaluation Methods

The first and second studies utilized different protocols. The first study used a semantic differential format, while the second study used a paired comparison format. Both experiments utilized a MATLAB interface to conduct the testing. After the subject filled out the consent form and read the study instructions, the subject used the MATLAB interface to complete the study. Before the juror began the actual testing, he listened to the training sounds for subjective *Pitch*, subjective *Duration* and subjective *Loudness*. The juror could listen to all of the training sounds as many times as he liked and in any order that he liked. Once the juror felt that they were comfortable with the training sounds, he began the testing protocol. The bipolar adjective pairs used in training sounds and the study were chosen or inspired by work performed by Richard Lyon to determine which adjective descriptors with which people naturally identify [4].

4.2.4.1 *Semantic Differential*

In the first study, the semantic differential protocol was used. In the semantic differential experiment, each sound sample is subjectively evaluated by the juror one time. The MATLAB program randomized the play order for each juror to prevent sample order bias.

The program played each sound sample to be evaluated one at a time. While the juror evaluated each sound sample, he could listen to the individual sound sample as many times as he liked. However, once the juror proceeded to the next sound sample, he could not go back. The juror rated each sound sample in each of the five categories of subjective *Naturalness*, subjective *Quality*, subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. The form completed for each sound sample is provided in Figure 23, where each category is given, along with the layman descriptors. The juror scored his perception of the sound sample in each of the five categories across a seven point scale. The sound samples tested in the semantic differential experiment were samples 1-24 of Table 3.

Sample 1		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Figure 23: Semantic differential sample evaluation form.

4.2.4.2 *Paired Comparison*

The second study utilized paired comparison. In a traditional paired comparison experiment, every sound sample is compared to every other sound sample, resulting in a total number of experiments of $n(n-1)$. To accommodate the full number of sound samples from the semantic differential experiment, a modified paired comparison approach was used. Instead of comparing every sound sample to every other sound sample, each sound sample was tested against a reference sound sample, which was the reference hardwood floor, sample 23. Sample 23 was selected as the reference sound sample, because it was a hardwood floor installation with a concrete subfloor in a floating installation. Consequently, the participation of the subfloor and installation method was the same as all of the laminate and engineered hardwood samples. One of the benefits of a paired comparison experiment is that an estimate of each juror's variability can be calculated from the repeated samples inherent in a paired comparison design. In order to keep that benefit, several laminate sound samples were tested against themselves randomly within the rest of the experiment. The MATLAB program randomized the play order for each juror to prevent sample order bias.

The program played each sound sample to be evaluated followed by the reference hardwood floor sound sample one at a time. While the juror evaluated how each sound sample compared to the reference hardwood sound sample, he could listen to the pair as many times as he liked. However, once the juror proceeded to the next sound sample pair, he could not go back. The juror rated each sound sample as it compared to the reference hardwood floor in each of the five categories of subjective *Naturalness*, subjective *Quality*, subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. The form completed for each sound sample pair is provided in Figure 24, where each category is given, along with the layman descriptors. The juror scored his perception of the sound sample in each of the five categories across an eleven point scale. The sound samples tested in the paired comparison experiment were samples 1-25 of Table 3.

Sample 1		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Figure 24: Paired comparison sample evaluation form.

4.3 Psychoacoustic Measures

A variety of potentially important metrics were employed for comparison to the sound jury results. Some metrics were coded in MATLAB as a part of this project. The complete programs are available in Appendix IX. Other metrics were used from the software package *PsySound3*. *PsySound3* is a MATLAB software package, developed by researchers at the University of Sidney and the University of New South Wales, which is used “for the analysis of sound recordings using physical and psychoacoustical algorithms” [30].

4.3.1 Objective Loudness

There are a variety of objective **Loudness** models available to represent the human perception of loudness. The objective **Loudness** metric used in this study was calculated according to *ISO 532 B: Acoustics. Method for calculating loudness level.*

The objective **Loudness** metric was calculated in MATLAB, and the program is provided in Appendix IX-2(f).

4.3.2 Objective Sharpness

Objective **Sharpness** is not a standardized metric, and there are several available versions of the metric. In this study, Zwicker and Fastl's approach was used. The objective **Sharpness** metric was calculated in MATLAB, and the program is provided in Appendix IX-2(g).

4.3.3 Objective Roughness

A number of models exist to calculate the perception of the roughness of a signal. The objective **Roughness** metric is valid for modulation frequencies above 20 Hz. The Daniel and Weber model was used in the study and was calculated using *Psysound3* [30].

4.3.4 Objective Fluctuation Strength

Objective **Fluctuation Strength** is similar to objective **Roughness**, but it is dominant in signals with modulation frequencies below 20 Hz. The objective **Roughness** was calculated from the objective **Dynamic Loudness** model of Chalupper and Fastl in *Psysound3* [30].

4.3.5 Objective Subjective Duration

The objective **Subjective Duration** was not directly calculated, because models of objective **Subjective Duration** are relatively simplistic and more commonly used in the perceived differences between sound bursts and pauses. Instead, the effect of objective **Subjective Duration** was assessed by plotting the physical duration of the sounds versus the subjective *Duration* of the sounds. A linear relationship between subjective *Duration* and physical duration would show that the objective **Subjective**

Duration is equal to the subjective *Duration*. A relationship with a curve that tails away from a linear relationship for the shorter sounds, as shown in Figure 10, would imply that the objective **Subjective Duration** may be an important characteristic of the sound.

4.3.6 Objective Perceived Pitch

The objective **Perceived Pitch** was evaluated through the tonality of the impulse and is proportional to the inverse of the objective **Spectral Flatness Measure** and was calculated by

$$Perceived\ \ Pitch = Tonality = {}^{\alpha}\!/_{SFM}$$

where α is an empirically determined constant and *SFM* is the objective **Spectral Flatness Measure**. The value of α was found by plotting the relationship between the subjective *Pitch* from the sound jury and the objective **Spectral Flatness Measure**.

4.3.6.1 *Objective Spectral Flatness Measure*

The objective **Spectral Flatness Measure** is proportional to the inverse of the tonality, which is an indicator of pitch in broadband sounds. The objective **Spectral Flatness Measure** was calculated in MATLAB with the code given in Appendix IX-2(c).

4.4 Sound Quality Index

The sound quality of hardwood and laminate flooring systems was established by comparing the subjective human perception of their sound to objective psychoacoustic metrics. The laboratory samples were constructed and tested with the hardware and method described in Section 0. The sound quality of the samples was evaluated by the experimental protocols detailed in the sound jury listening tests using several subjective metrics. The objective psychoacoustic metrics were calculated using the methods presented in Section 4.3 and compared to the subjective metrics from the sound jury. A sound quality index was constructed from relationships established from comparisons between the subjective and objective metrics.

A sound quality index was constructed from the results of the sound jury, so that the sound quality of future samples can be inferred from the sound quality index established in this study. The sound quality index was developed in several steps. Building the sound quality index required that the data be normalized and then correlated to all other metrics, both subjective and objective. All significant correlations were included in a regression analysis for each sound jury subjective metric. An index was constructed for each subjective sound jury metric. In addition to the sound quality index, a factor analysis and individual sample t-tests are provided as post-hoc tests.

4.4.1 Normalize Data

Jurors will use the same scale during a sound jury differently. To create equal weightings between all jurors, the scores of each juror were normalized. The normalized scores for each evaluation category (e.g. subjective *Loudness*, subjective *Pitch*, subjective *Quality*) have a mean of zero and a standard deviation of one.

4.4.2 Correlation Coefficients

The Pearson product moment correlation coefficient, or sample correlation coefficient, was calculated for each metric. The correlation coefficients were calculated using Microsoft Excel statistics analysis toolpack.

4.4.3 Critical Correlation Coefficient Level

A critical correlation level was established based on the number of degrees of freedom, *df*. All correlations higher than the critical correlation level were established as significant relationships. All relationships with correlations lower than the critical correlation level were discarded, because they are statistically shown to be relationships by chance [8].

4.4.4 ANOVA

The ANOVA test was performed on the normalized data of each subjective metric from the paired comparison study. The test was performed in *Microsoft Excel*, using the statistical analysis toolpack. The test was a single factor ANOVA with α=0.05.

4.4.4.1 *Regression Analysis*

The significant objective metrics associated with each subjective metric were used to create a model of that subjective metric. The data for the subjective metrics was composed of the normalized results. A multiple linear regression model was developed with *statistiXL*.

4.4.5 Factor Analysis

In addition to a regression analysis, a factor analysis was used to determine primary relationships between variables. The *statistiXL* package was used to conduct the factor analysis. The factor analysis helped understand the interrelationships between the metrics, both objective and subjective, used in the study. A factor analysis "takes thousands and potentially millions of measurements and qualitative observations and resolves them into distinct patterns of occurrence" [23].

The factor analysis output was a correlation matrix. A *varimax* rotated factor loading operation was performed on the factor analysis matrix. The *varimax* operation orthogonally rotated the factor loadings to create clear clusters of relationships [23].

4.4.6 Post Hoc t-test

The t-test was performed in *Microsoft Excel*. The TTEST function was used to compare each possible combination of samples in the sound jury study. The normalized sound jury results were used in the sample comparisons. The number of tails used in the t-test calculation was 2, and the samples were assumed to be unequal variances.

CHAPTER 5. RESULTS AND DISCUSSION

5.1 Sound Jury

The results of both the first sound jury and second sound jury are presented. The first sound jury utilized a semantic differential protocol, while the second sound jury used a paired comparison protocol. The first study resulted in insufficient statistical performance, necessitating a second study. As will be explained below, the second study also failed to obtain the desired level of statistical performance.

5.1.1 Semantic Differential Experiment

The semantic differential experiment, conducted on the Georgia Tech campus, was conducted to reveal how a panel of jurors perceives the sound quality and acoustical traits of different laminate flooring composites. The objective of this experiment was to demonstrate how the psychoacoustical measures of subjective *Pitch*, subjective *Duration*, and subjective *Loudness* relate to the sound juror's overall impression of that floor's subjective *Quality* and subjective *Naturalness*.

5.1.1.1 ***Subjective Quality***

The jurors were asked to rate the subjective *Quality* of the flooring composites between low and high. The juror was not provided a concrete definition of what the metric "Quality Floor" was asking for, so that the juror was not influenced by another individual's definition of subjective *Quality*. In the first study, a score of 4.00 indicated average subjective *Quality*.

Figure 25 shows the subjective *Quality* of all flooring samples. The tick marks represent the 95% confidence interval associated with the mean. The subjective *Quality* of the reference hardwood, in gray, scored second highest, at 4.40. All other flooring composites scored below 4.40, except one that scored a 4.44.

The high score in subjective *Quality* for the hardwood sample was encouraging. A hardwood sample that scored highly in subjective *Quality* showed that the jury was able to pick out the actual hardwood over laminate samples; however, the confidence intervals associated with all of the scores demonstrated that a lower variance would be needed to obtain statistically conclusive results.

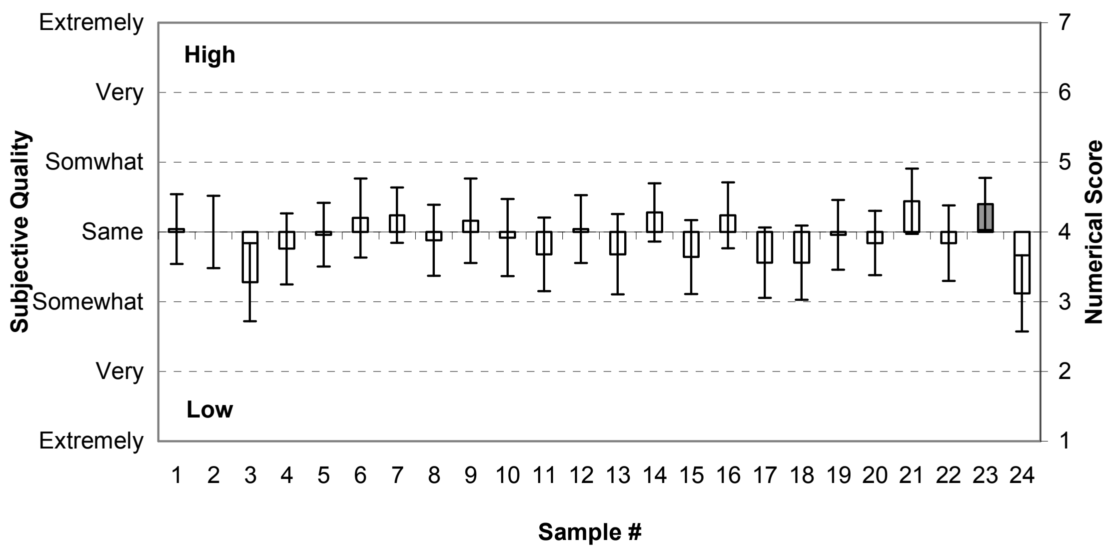

Figure 25: Semantic differential experiment subjective *Quality* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.1.2 ***Subjective Naturalness***

The jurors were asked to rate the subjective *Naturalness* of the flooring composites between artificial and natural. The juror was not provided a concrete definition of what the metric subjective *Naturalness* was asking for, so that the juror was not influenced by another individual's definition of subjective *Naturalness*. In the first study, a score of 4.00 indicated average subjective *Naturalness*.

Figure 26 shows the subjective *Naturalness* of all flooring samples. The tick marks represent the 95% confidence interval associated with the mean. The subjective *Naturalness* of the reference hardwood, in gray, scored third highest, at 4.48. All other flooring composites scored below 4.48, except two that scored a 4.84 and a 4.68.

The high score in subjective *Naturalness* was encouraging. As with the subjective *Quality* metric, the high subjective *Naturalness* score of the hardwood sample showed that there was a perceived advantage of a hardwood over most laminate samples; however, the confidence intervals associated with all of the scores demonstrated that a lower variance would be needed to obtain statistically conclusive results.

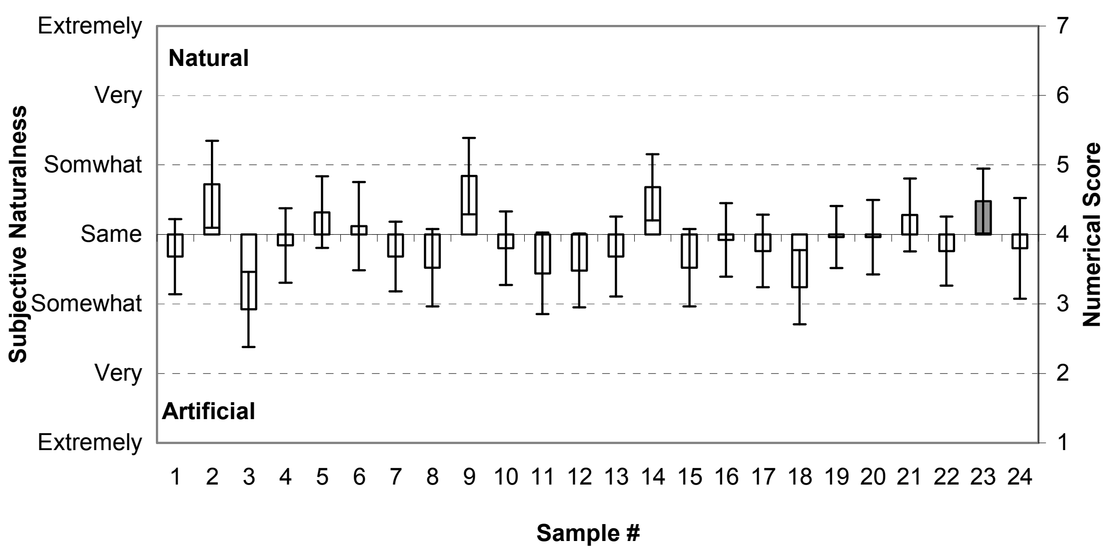

Figure 26: Semantic differential experiment subjective *Naturalness* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.1.3 ***Subjective Pitch***

The jurors were asked to rate the subjective *Pitch* of the flooring composites between dull and bright. The juror was provided a description of what subjective *Pitch* is defined as, as well a both a qualitative example and a training sound demonstrating the ranges of subjective *Pitch* that would be heard in the study. In the first study, a score of 4.00 indicated that the sample was neither bright nor dull.

Figure 27 shows the subjective *Pitch* of all flooring samples. The tick marks represent the 95% confidence interval associated with the mean. The subjective *Pitch* of the reference hardwood is in gray.

The subjective *Pitch* of the reference hardwood was perceived to be a little dull by the jury with a score of 3.52. Unlike subjective *Quality* and subjective *Naturalness* where a high score was sought for the reference hardwood sample, the score of the reference hardwood sample for the subjective *Pitch* metric was arbitrary. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Pitch* of the reference hardwood indicated that the laminate composite represents the subjective *Pitch* of a hardwood floor well. With that in mind, Figure 27 shows that the subjective *Pitch* of samples 13 and sample 1 most closely matched the subjective *Pitch* of the reference hardwood floor, with scores of 3.64 and 3.84 respectively. However, the confidence intervals associated with all of the scores demonstrated that a lower variance would be needed to obtain statistically conclusive results.

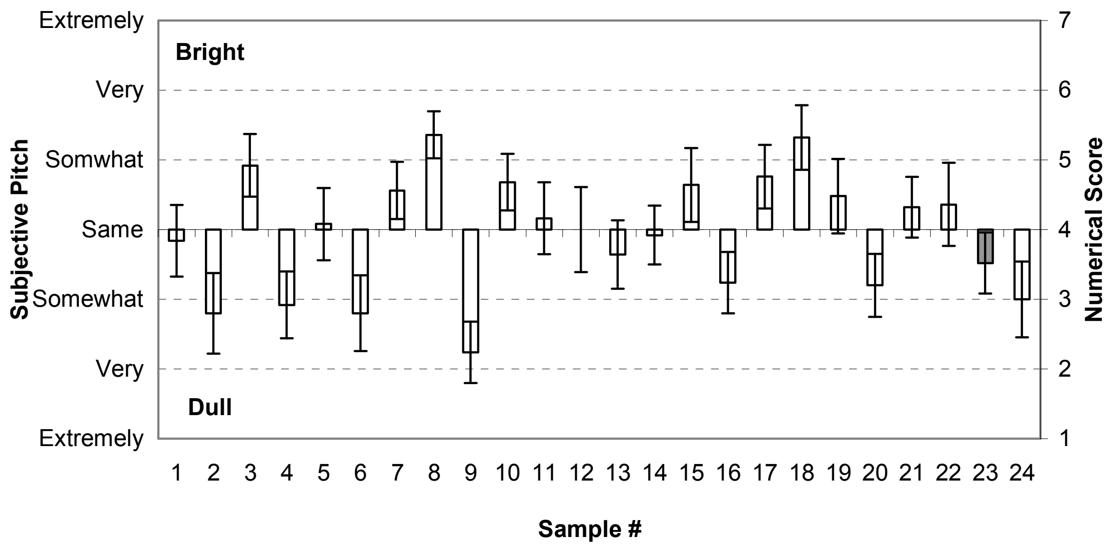

Figure 27: Semantic differential experiment subjective *Pitch* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.1.4 ***Subjective Duration***

The jurors were asked to rate the subjective *Duration* of the flooring composites between sharp and hollow. The juror was provided a description of what subjective *Duration* is defined as, as well a both a qualitative example and a training sound demonstrating the ranges of subjective *Duration* that would be heard in the study. In the first study, a score of 4.00 indicated that the sample was neither hollow nor sharp.

Figure 28 shows the subjective *Duration* of all flooring samples. The tick marks represent the 95% confidence interval associated with the mean. The subjective *Duration* of the reference hardwood is in gray.

The subjective *Duration* of the reference hardwood was perceived to be slightly hollow by the jury with a score of 4.08. Unlike subjective *Quality* and subjective *Naturalness* where a high score was sought for the reference hardwood sample, the score of the reference hardwood sample for the subjective *Duration* metric was arbitrary. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Duration* of the reference hardwood indicated that the laminate composite represents the subjective *Duration* of a hardwood floor well. Figure 28 shows that the subjective *Duration* of most of the samples closely matched the subjective *Duration* of the reference hardwood floor. However, the confidence intervals associated with all of the scores demonstrated that a lower variance would be needed to obtain statistically conclusive results.

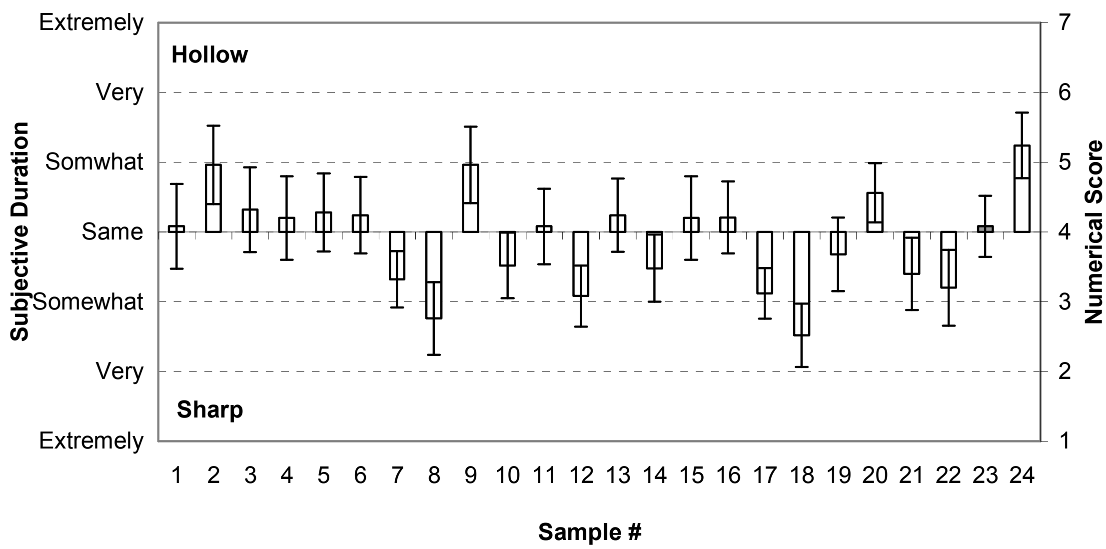

Figure 28: Semantic differential experiment subjective *Duration* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.1.5 ***Subjective Loudness***

The jurors was asked to rate the subjective *Loudness* of the flooring composites between soft and loud. The juror was provided a description of what subjective *Loudness* is defined as, as well a both a qualitative example, and a training sound demonstrating the ranges of subjective *Loudness* that would be heard in the study. In the first study, a score of 4.00 indicated that the sample was neither loud nor soft.

Figure 29 shows the subjective *Loudness* of all flooring samples. The tick marks represent the 95% confidence interval associated with the mean. The subjective *Loudness* of the reference hardwood is in gray.

The subjective *Loudness* of the reference hardwood was perceived to be slightly soft by the jury with a score of 3.96. Unlike subjective *Quality* and subjective *Naturalness* where a high score was sought for the reference hardwood sample, the score of the reference hardwood sample for the subjective *Loudness* metric was arbitrary. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Loudness* of the reference hardwood indicated that the laminate composite represents the subjective *Loudness* of a hardwood floor well. Figure 29 shows the subjective *Loudness* of most of the samples closely matches the subjective *Loudness* of the reference hardwood floor. However, the confidence intervals associated with all of the scores demonstrated that a lower variance would be needed to obtain statistically conclusive results.

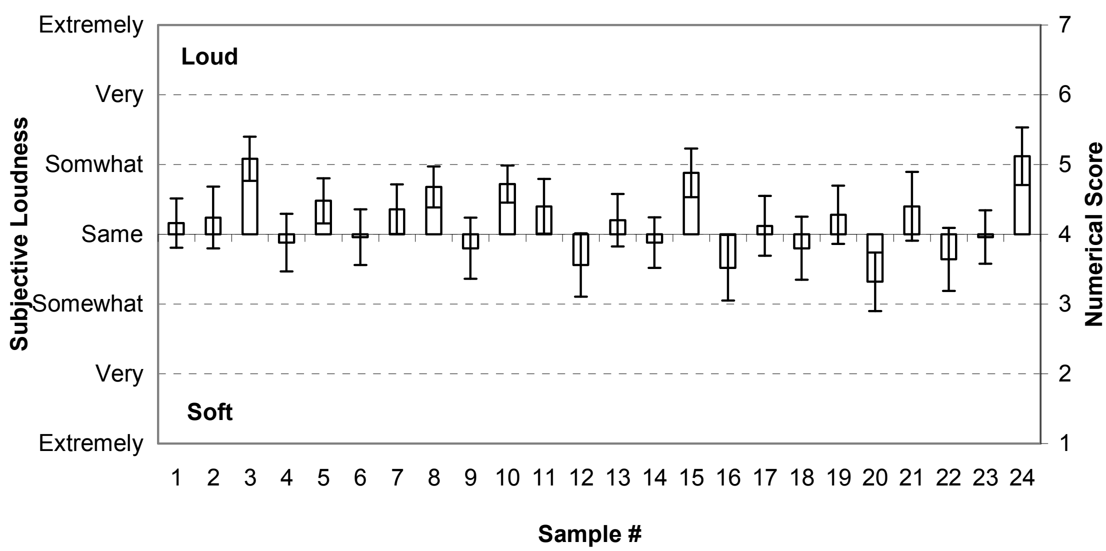

Figure 29: Semantic differential experiment subjective *Loudness* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.1.6 ***Semantic Differential Experiment Summary***

The semantic differential experiment demonstrated that jurors were able to differentiate acoustical traits of laminate flooring samples from a sound jury study. However, the study failed to establish a high level of statistical significance. Review of the responses showed that jurors were reluctant to use the more extreme graduations on the response rating scale. This is a common problem in jury evaluations. A solution is to increase the number of graduations in the response scale and use a different method for the sound jury.

Based on the results above, a second study was needed. In order to improve upon the precision achieved in the semantic differential study, a modified paired comparison study was used. In the modified paired comparison study, all of the flooring samples were compared to the reference hardwood flooring sample, sample 23. By comparing the flooring samples to a reference sample instead of comparing every sample against every other sample, all of the samples from the semantic differential study could be used.

5.1.2 Paired Comparison Experiment

The paired comparison experiment, conducted at the sponsoring company's facility was employed to improve upon the statistics from the first experiment. Additionally, the paired comparison experiment was intended to show the repeatability of the results from the first experiment. In the paired comparison experiment, all of the samples were compared to a reference hardwood flooring sample, which was sample 23. The juror responses should have been more precise, because the juror was given a sound to compare directly to another sound which was not as open-ended as a semantic differential presentation. Moreover, the number of graduations was increased from 6 to

11 on the response scale to encourage the jurors to use more extreme ratings when performing the study. The same format as the paired comparison experiment was used, except the evaluation task became a similar/dissimilar evaluation. In the paired comparison format, a score of 1 or 11 was very different as the reference hardwood sample, and a score of 6 was the same as the reference hardwood sample. Also, sample 25 was introduced in the paired comparison study. The sponsoring company expressed an interest in testing the hardwood floor in a glue-down installation on the concrete subfloor, so sample 25 was created to test this installation.

5.1.2.1 ***Subjective Quality***

The jurors were asked to rate the subjective *Quality* of the flooring composites as they compared to the reference hardwood flooring sample. The juror was not provided a concrete definition of what the metric "Quality Floor" was asking for, so that the juror was not influenced by another individual's definition of subjective *Quality*. In the study, a score of 6.00 indicated a subjective *Quality* equal to the reference hardwood floor.

Figure 30 shows the subjective *Quality* of all flooring samples as they compared to the reference hardwood flooring sample. The tick marks represent the 95% confidence interval associated with the mean. The reference hardwood, compared to itself, should have scored a 6.00, and its actual score was scored a 5.91. Several other flooring samples scored slightly higher than the reference hardwood sample, but their 95% confidence intervals all included 6.00. The majority of the samples scored lower in subjective *Quality* than the reference hardwood floor.

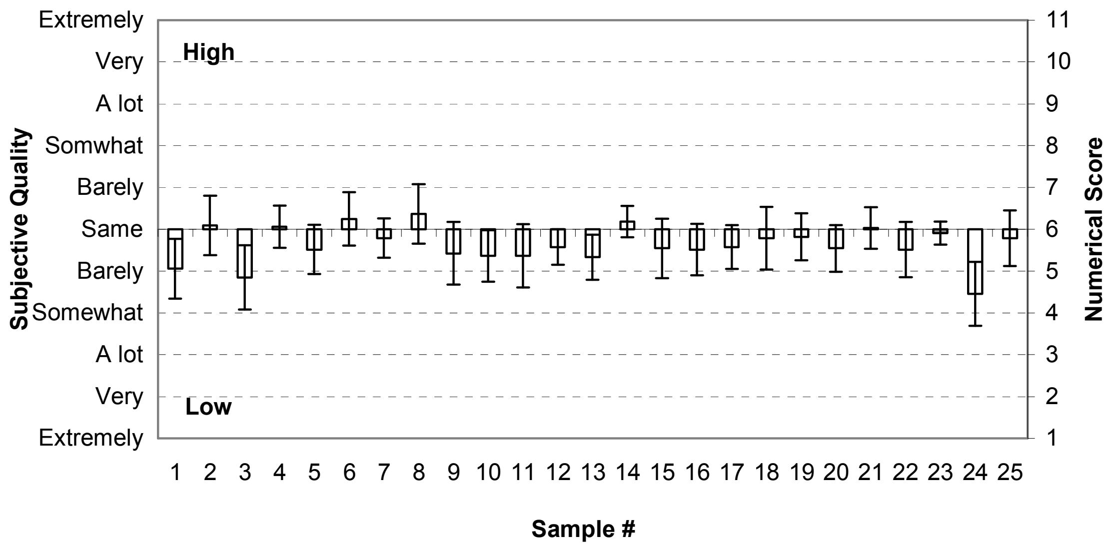

Figure 30: Paired comparison experiment subjective *Quality* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.2.2 ***Subjective Naturalness***

The jurors were asked to rate the subjective *Naturalness* of the flooring composites as they compared to the reference hardwood flooring sample. The juror was not provided a concrete definition of what the metric subjective *Naturalness* was asking for, so that the juror was not influenced by another individual's definition of subjective *Naturalness*. In the study, a score of 6.00 indicated a subjective *Naturalness* equal to the reference hardwood floor.

Figure 31 shows the subjective *Naturalness* of all flooring samples as they compare to the reference hardwood flooring sample. The tick marks represent the 95% confidence interval associated with the mean. The reference hardwood, compared to itself, should have scored a 6.00, and its actual score was scored a 5.85. Several other flooring samples scored slightly higher than the reference hardwood sample, but their

95% confidence intervals all included 6.00. The majority of the samples scored lower in subjective *Naturalness* than the reference hardwood floor.

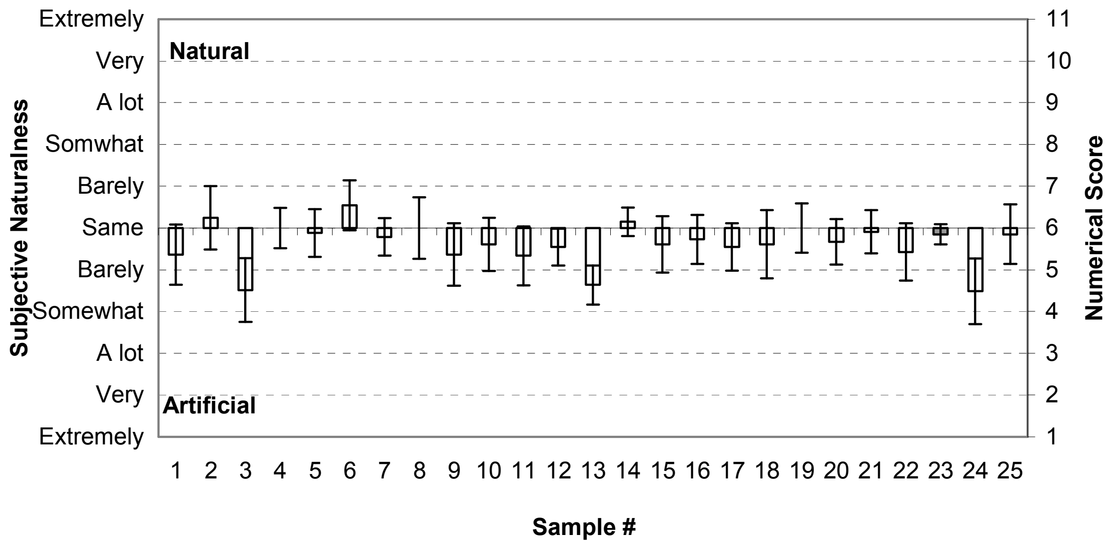

Figure 31: Paired comparison experiment subjective *Naturalness* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.2.3 ***Subjective Pitch***

The jurors were asked to rate the subjective *Pitch* of the flooring composites as they compared to the reference hardwood flooring sample. The juror was provided a description of what subjective *Pitch* was defined as, as well a both a qualitative example and a training sound demonstrating the ranges of subjective *Pitch* that would be heard in the study. In the study, a score of 6.00 indicated a perceived *Pitch* equal to the reference hardwood floor.

Figure 32 shows the subjective *Pitch* of all flooring samples as they compare to the reference hardwood flooring sample. The tick marks represent the 95% confidence interval associated with the mean. The reference hardwood, compared to itself, should have scored a 6.00, and its actual score was scored a 6.03. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Pitch* of the reference hardwood indicated that the laminate composite represents the *Pitch* of a hardwood floor well. Figure 32 shows that the subjective *Pitch* of several samples closely matched the subjective *Pitch* of the reference hardwood floor. There was roughly an even split with samples that scored above or below the subjective *Pitch* of the reference hardwood floor. The even split between higher and lower *Pitch* was an interesting result. As stated by the sponsoring company, most complaints about laminate flooring were based on a high pitched, clicky quality to the floors. With the samples that were tested as part of the study, roughly half of the samples tested had a more dull subjective *Pitch* than the reference hardwood.

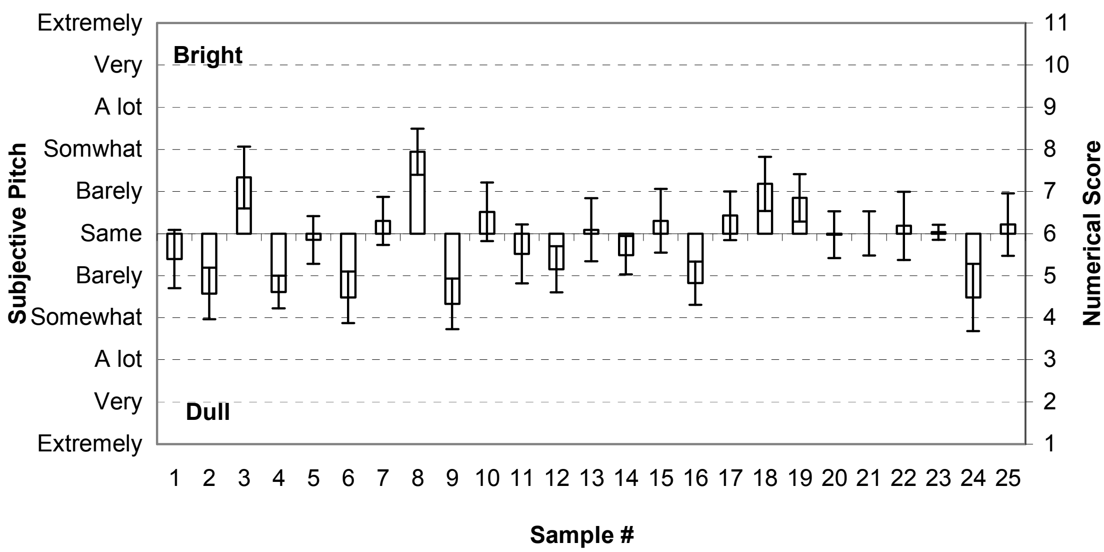

Figure 32: Paired comparison experiment subjective *Pitch* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.2.4 ***Subjective Duration***

The jurors were asked to rate the subjective *Duration* of the flooring composites as they compared to the reference hardwood flooring sample. The juror was provided a description of what subjective *Duration* was defined as, as well a both a qualitative example, and a training sound demonstrating the ranges of subjective *Duration* that would be heard in the study. In the study, a score of 6.00 indicated a subjective *Duration* equal to the reference hardwood floor.

Figure 33 shows the subjective *Duration* of all flooring samples as they compare to the reference hardwood flooring sample. The tick marks represent the 95% confidence interval associated with the mean. The reference hardwood, compared to itself, should have scored a 6.00, and its actual score was scored a 6.09. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Duration* of the reference hardwood indicated that the laminate composite represents the subjective *Duration* of a hardwood floor well. Figure 33 shows that the subjective *Duration* of several samples closely matched the subjective *Duration* of the reference hardwood floor. Most of the samples in the study were found to be more hollow in subjective *Duration* than the reference hardwood floor.

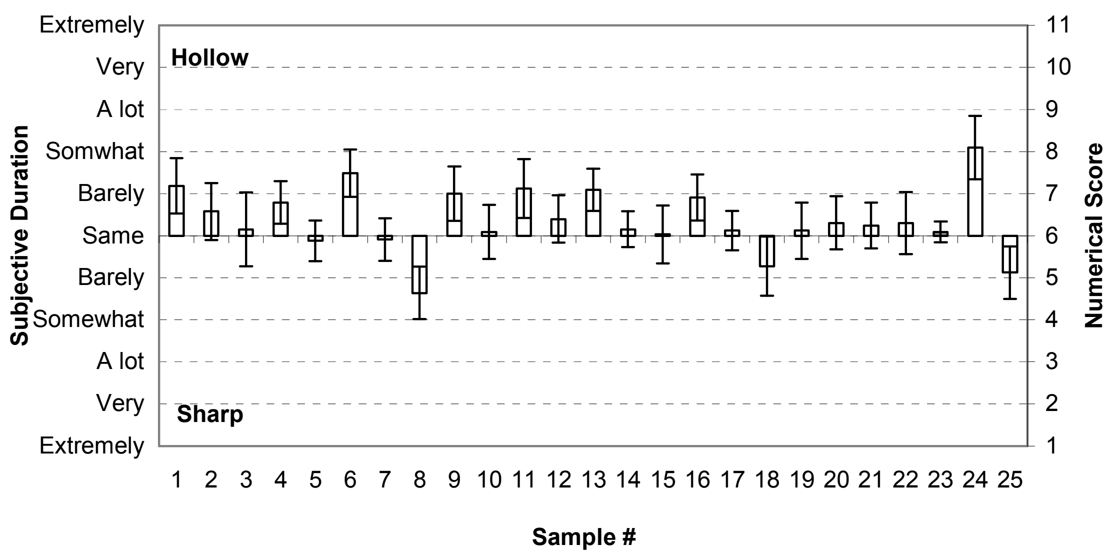

Figure 33: Paired comparison experiment subjective *Duration* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.2.5 ***Subjective Loudness***

The jurors were asked to rate the subjective *Loudness* of the flooring composites as they compared to the reference hardwood flooring sample. The juror was provided a description of what subjective *Loudness* was defined as, as well a both a qualitative example and a training sound demonstrating the ranges of subjective *Loudness* that would be heard in the study. In the study, a score of 6.00 indicated a subjective *Loudness* equal to the reference hardwood floor.

Figure 34 shows the subjective *Loudness* of all flooring samples as they compare to the reference hardwood flooring sample. The tick marks represent the 95% confidence interval associated with the mean. The reference hardwood, compared to itself, should have scored a 6.00, and its actual score was scored a 6.12. As part of a potential sound quality index, the ability of a laminate composite to score near the subjective *Loudness* of the reference hardwood indicated that the laminate composite represents the subjective *Loudness* of a hardwood floor well. Figure 34 shows the subjective *Loudness* of several samples closely matched the subjective *Loudness* of the reference hardwood floor. Most of the samples in the study were found to be less loud than the reference hardwood floor.

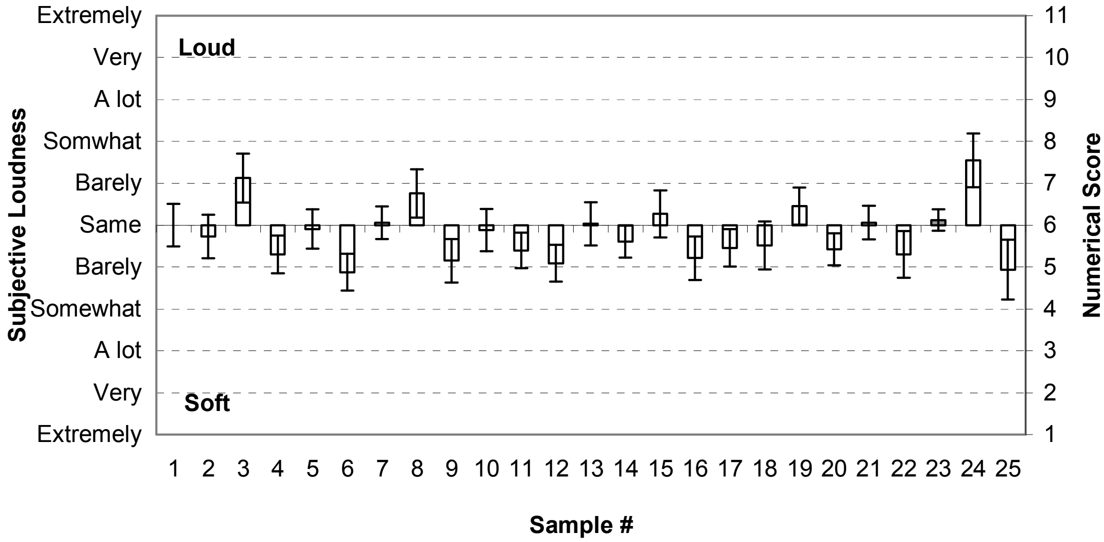

Figure 34: Paired comparison experiment subjective *Loudness* of the flooring composites with the reference hardwood floor in gray. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.1.2.6 ***Paired Comparison Experiment Summary***

The purpose of the paired comparison study was to improve the precision of the results from the semantic differential study. Table 5 provides a comparison of the statistics between the two studies. The comparison is based made on the percentage of the samples in the study that were shown to be statistically significantly different from the reference hardwood sample, sample 23, in a post-hoc t-test to a 95% level of confidence. Generally, the paired comparison study failed to increase the precision of the semantic differential study. Specifically, the percentages of statistically significant results for the overall results were closely matched between the two studies. Either study could be used for all further analysis, since there was no real statistical advantage of one study over the other.

Table 5: Comparison between the semantic differential and paired comparison study significance level (t-test, $p<0.05$).

	% Statistically Significant	
	Semantic Differential	Paired Comparison
Quality Floor	15	22
Naturalness	29	25
Pitch	61	60
Duration	50	41
Loudness	46	52

The results from the second study were selected for all further analysis, based on the more closed procedure used in acquiring the juror responses. The method for the first experiment prompted the juror for an open-ended impression of the sound, while the second study provided a reference sound for direct comparison. The results of both studies generally agreed with each other, but there were some small differences. In light of these small differences, the second study will be used based on the more closed nature of the sound jury method.

5.1.3 Flooring Material Results

The impact of each type of flooring material on sound quality was analyzed. First, the flooring material was broken into all laminate flooring samples and all engineered flooring samples. These two groups were then plotted in Figure 35 next to samples 23 and 25, which are the reference hardwood floor and the glue-down hardwood. Because the results for the laminate and engineered flooring encompassed 11 individual samples, the confidence interval associated with each group is smaller than that of an individual sample. All determinations of either being statistically similar or statistically different are based on a 95% level of confidence.

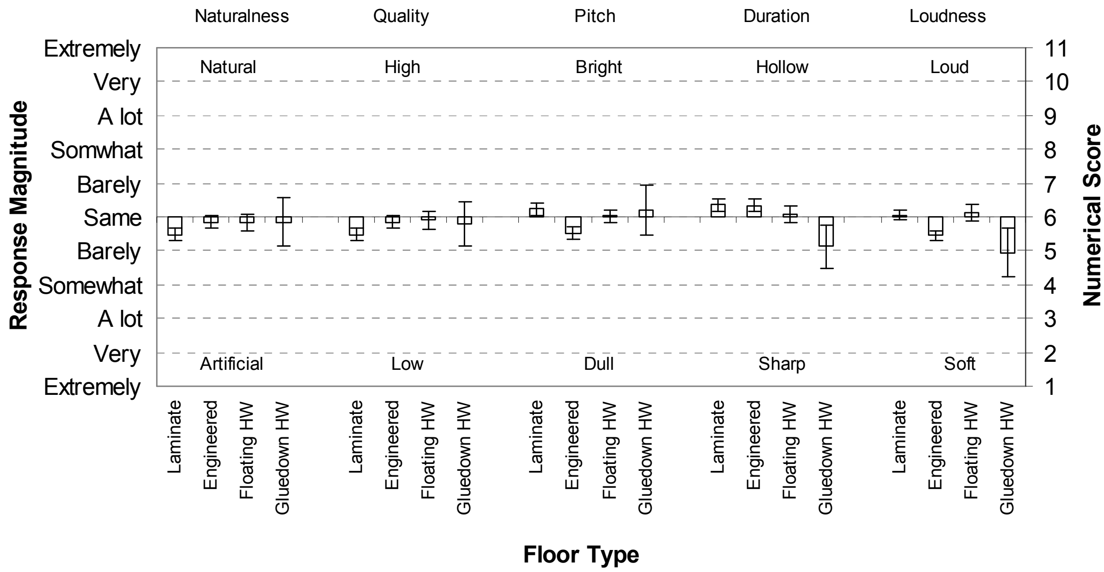

Figure 35: Subjective performance of flooring types compared to the reference floating hardwood (Sample 23) and glue-down hardwood (Sample 24) with 95% confidence intervals. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

The laminate flooring material scored significantly lower in subjective *Quality* and subjective *Naturalness* than the reference hardwood sample. The engineered hardwood material and the glue-down hardwood were statistically similar to the reference hardwood in subjective *Quality* and subjective *Naturalness*. The subjective *Pitch* of the laminate hardwood material and the glue-down hardwood were statistically similar to the reference hardwood floor, and the engineered hardwood material was significantly duller than the reference hardwood. The subjective *Duration* of the laminate and engineered flooring materials was statistically similar to the reference hardwood floor. The glue-down hardwood sample was statistically sharper than the reference hardwood floor. The subjective *Loudness* of the laminate flooring material was statistically similar to the reference hardwood floor, while the engineered hardwood material and the glue-down hardwood were evaluated as being significantly softer than the reference hardwood floor.

5.1.4 Underlayment Material Results

The impact of each type of underlayment material on sound quality was analyzed. The underlayment materials were broken into different classifications, as provided by the sponsoring company. A general description is listed for each material classification in Figure 36. All of the material classifications were compared to samples 23 and 25, which are the reference hardwood floor and the glue-down hardwood. Because the results for the underlayment types encompass multiple underlayments, the confidence interval associated with each group was smaller than that of an individual sample.

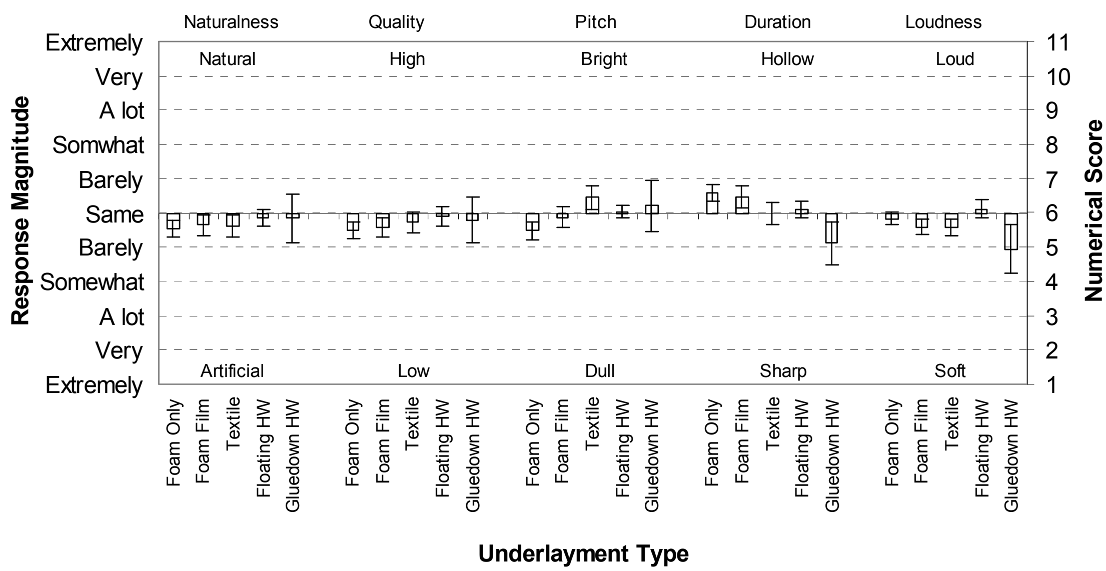

Figure 36: Subjective performance of underlayment types compared to the reference floating hardwood (Sample 23) and glue-down hardwood (Sample 24) with 95% confidence intervals. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

All underlayments were statistically similar to both the reference hardwood floor and the glue-down hardwood in subjective *Naturalness* and subjective *Quality*. The subjective *Pitch* of the foam underlayments was duller than the reference hardwood, while the foam/film and textile underlayments were statistically similar along with the glue-down hardwood floor sample. All underlayments were statistically similar to the reference hardwood floor in subjective *Duration*, but the glue-down hardwood was perceived as sharper. The subjective *Loudness* of all of the underlayments was statistically similar to the reference hardwood sample, while the glue-down hardwood appears to be softer.

5.1.5 Male/Female Bias Results

With the results from the paired comparison study, the presence of a male/female bias for flooring perception could be reviewed. The perception of all floors is given for male and female listeners in Figure 37. No statistically significant bias existed between male and female listeners for the flooring materials.

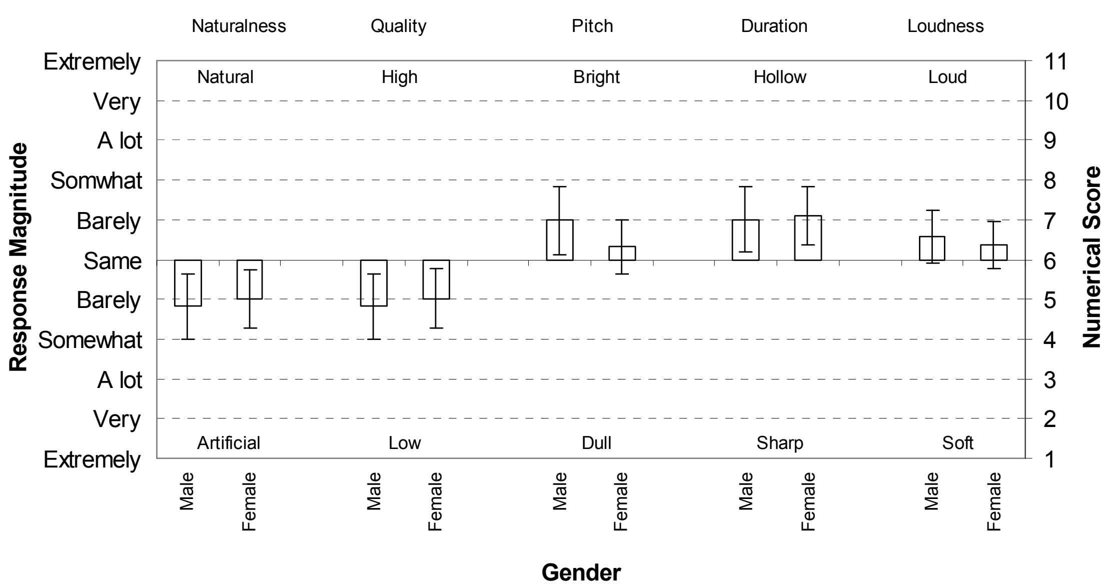

Figure 37: Subjective performance of all flooring samples for male and female listeners with 95% confidence intervals. The qualitative magnitude from the sound jury and numerical magnitude are provided on the y-axes.

5.2 Psychoacoustic Measures

All data for the calculated psychoacoustic metrics for each sample are presented in this section. The calculated value of each metric was generated from the single sample used in the sound jury experiments. The objective metrics were then used in the sound quality index to describe the sound jury perception of the flooring samples.

5.2.1 Objective Loudness

The objective **Loudness** of each sample is given in Figure 38 with the reference hardwood floor is shown in white. The reference hardwood floor possessed an objective **Loudness** of 3.823 Sones. The objective **Loudness** value of the reference hardwood was neither good nor bad. As a calculated input to a sound quality index, a desired characteristic of a laminate composite should be to have an objective **Loudness** similar to that of the reference hardwood floor.

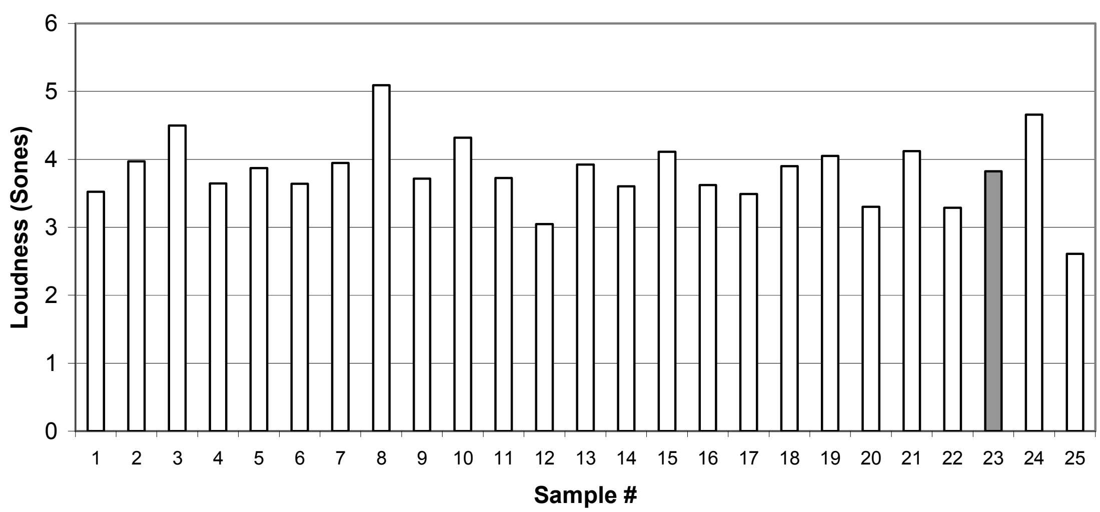

Figure 38: Objective **Loudness** metric for each flooring composite sample with the reference hardwood sample in white.

5.2.2 Objective Sharpness

The objective **Sharpness** of each sample is given in Figure 39 with the reference hardwood floor is shown in white. The reference hardwood floor possessed an objective **Sharpness** of 1.316 Acum. The objective **Sharpness** value of the reference hardwood was neither good nor bad. As a calculated input to a sound quality index, a desired characteristic of a laminate composite should be to have an objective **Sharpness** similar to that of the reference hardwood floor.

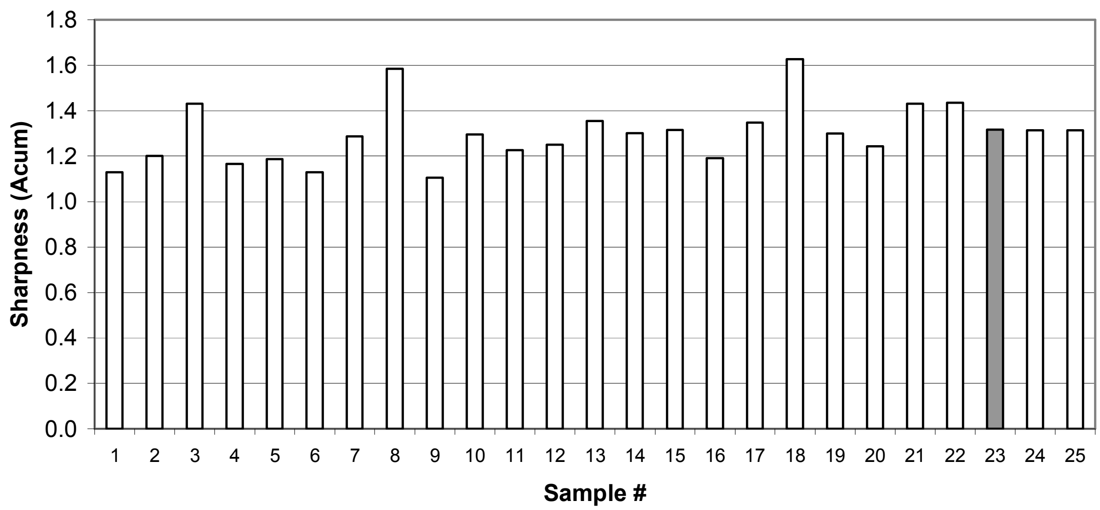

Figure 39: Objective **Sharpness** metric for each flooring composite sample with the reference hardwood sample in white.

5.2.3 Objective Roughness

The average objective **Roughness** of each sample is given in Figure 40 with the reference hardwood floor is shown in white. The reference hardwood floor possessed an objective **Roughness** of 2.12 Asper. The average objective **Roughness** value of the reference hardwood was neither good nor bad. As a calculated input to a sound quality index, a desired characteristic of a laminate composite should be to have an average objective **Roughness** similar to that of the reference hardwood floor.

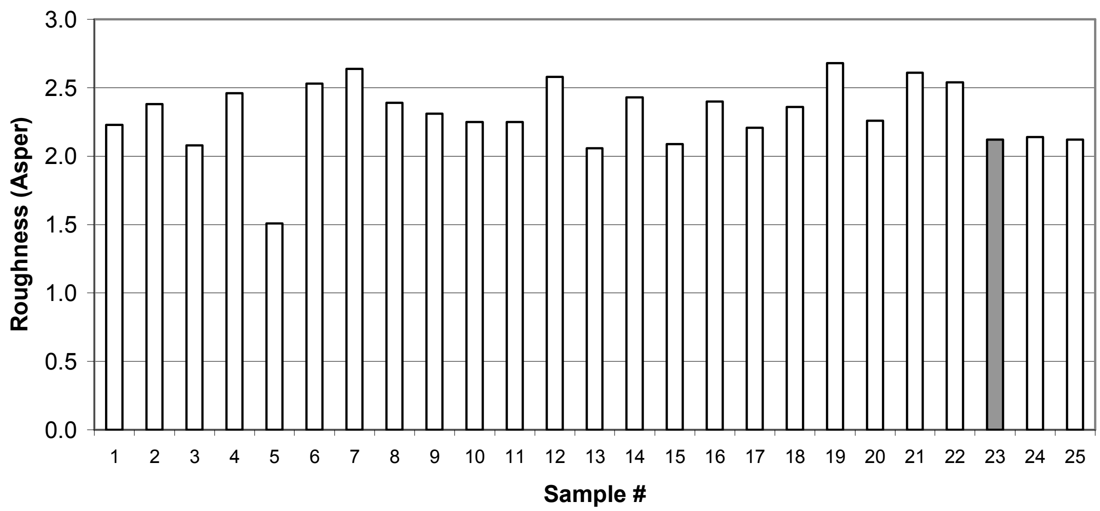

Figure 40: Objective **Roughness** metric for each flooring composite sample with the reference hardwood sample in white.

5.2.4 Objective Fluctuation Strength

The average objective **Fluctuation Strength** of each sample is given in Figure 41 with the reference hardwood floor is shown in white. The reference hardwood floor possessed a calculated average objective **Fluctuation Strength** of 3.64 Vacils. The average objective **Fluctuation Strength** value of the reference hardwood was neither good nor bad. As a calculated input to a sound quality index, a desired characteristic of a laminate composite should be to have an average objective **Fluctuation Strength** similar to that of the reference hardwood floor.

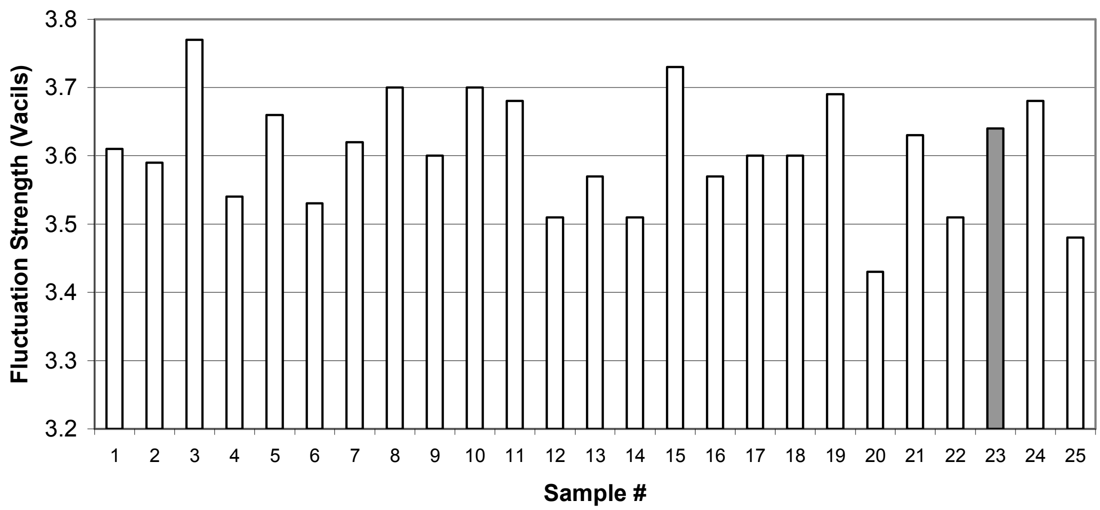

Figure 41: Objective **Fluctuation Strength** metric for each flooring composite sample with the reference hardwood sample in white.

5.2.5 Objective Subjective Duration

The presence of a nonlinear relationship between the objective **Subjective Duration** and physical duration was checked by plotting the subjective *Duration* from the paired comparison study versus the metric that best represents the perception of subjective *Duration*, which was found in the critical correlation for subjective *Duration* in Table 7. Table 7 is discussed in detail in Section 5.3.3. The subjective *Duration* was plotted versus objective **Sharpness** and both a linear and an exponential regression were performed. The results show that the exponential regression had a R^2 of 0.3388, while the linear regression had a R^2 of 0.4425 as shown in Figure 42. Also, the exponential regression was nearly linear. The flatness and low correlation of the exponential regression show that the effect of the objective **Subjective Duration** of short, impulse signals was very small or non-existent in this study.

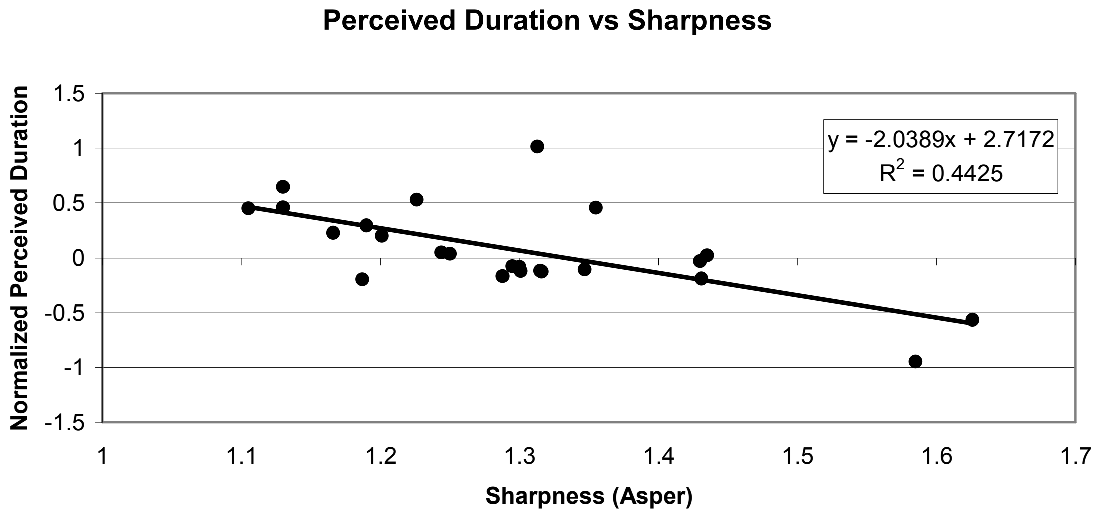

Figure 42: Relationship between the normalized subjective *Duration* and the objective **Sharpness** of the flooring samples.

5.2.6 Objective Perceived Pitch

The objective **Perceived Pitch** of the impulse sound is simply the slope of the relationship, or α, between the tonality, or inverse of the objective **Spectral Flatness Measure**, and the subjective *Pitch* of the normalized sound jury responses. The calculated α for this particular experiment's pitch relation was 0.0281 which was taken from the linear regression shown in Figure 43. Because the tonality and objective **Perceived Pitch** of the sounds used in the experiment are linearly related to the objective **Spectral Flatness Measure**, the objective **Spectral Flatness Measure** values will be used directly in all further results.

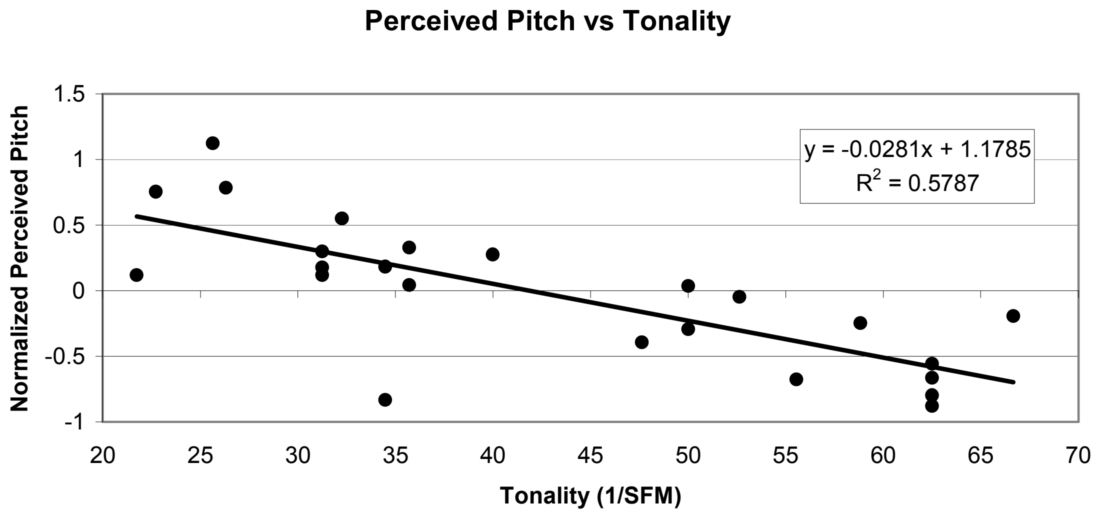

Figure 43: Relation ship between the normalized subjective *Pitch* and the tonality of the flooring samples.

5.2.7 Objective Spectral Flatness Measure

The objective **Spectral Flatness Measure** of each sample is given in Figure 44 with the reference hardwood floor is shown in white. The reference hardwood floor possessed an objective **Spectral Flatness Measure** 0.032. The objective **Spectral Flatness Measure** value of the reference hardwood was neither good nor bad. As a calculated input to a sound quality index, a desired characteristic of a laminate composite should be to have an objective **Spectral Flatness Measure** similar to that of the reference hardwood floor.

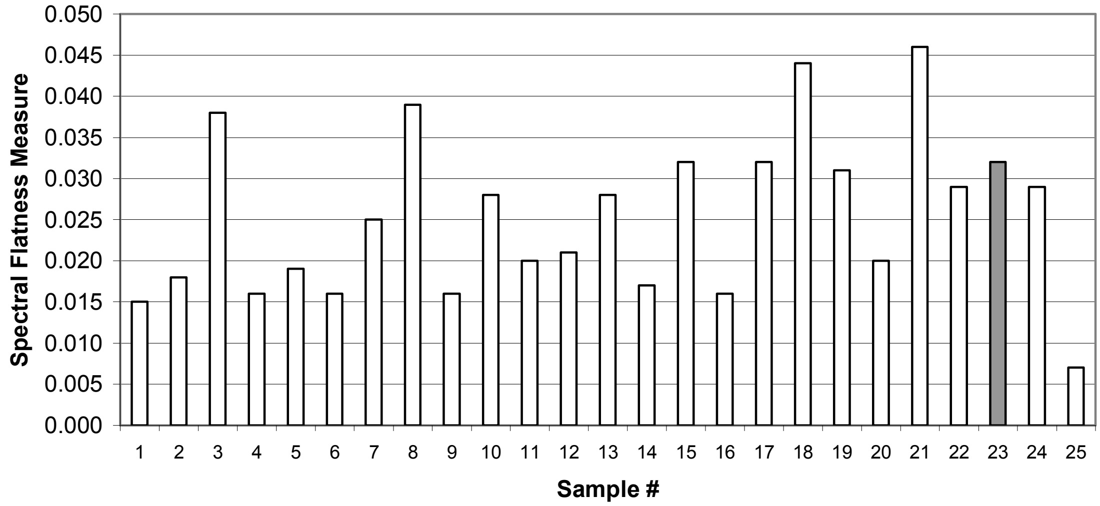

Figure 44: Objective **Spectral Flatness Measure** of the power spectrum of pressure with the reference hardwood sample in white.

5.3 Sound Quality Index

The sound quality index was constructed by associating the calculated objective psychoacoustic metrics with the perceived subjective metrics. The sound quality index was constructed to create an equation to describe the sound jury's perception of each subjective metric from calculated metrics.

5.3.1 Normalize Data

First, the subjective results for subjective *Quality*, subjective *Naturalness*, subjective *Pitch*, subjective *Duration*, and subjective *Loudness* had to be normalized. The normalized result for each metric is given in Appendix II. Each metric is presented with a 95% confidence interval, shown with tick marks on the plots.

5.3.2 Correlation Coefficients

The Pearson product moment correlation coefficient, or sample correlation coefficient, was calculated for the objective metrics and normalized subjective metrics. The results are given in Table 6.

Table 6: Pearson product moment correlation coeffiecients for objective and subjective metrics from the paired comparision study.

Pearson Correlation Coefficient		Objective (calculated)					Subjective (from sound jury)				
		Loudness	**Sharpness**	**SFM Pmag**	**Fluctuation**	**Roughness**	*Pitch*	*Duration*	*Loudness*	*Natural*	*Quality*
Objective (calculated)	**Loudness**	1.000									
	Sharpness	0.394	1.000								
	SFM Pmag	0.622	0.810	1.000							
	Fluctuation	0.789	0.251	0.540	1.000						
	Roughness	-0.081	0.089	0.106	-0.268	1.000					
Subjective (from sound jury)	*Pitch*	0.315	0.793	0.654	0.371	-0.045	1.000				
	Duration	-0.049	-0.634	-0.348	-0.077	0.021	0.804	1.000			
	Loudness	0.808	0.330	0.548	0.743	-0.223	-0.321	-0.026	1.000		
	Natural	-0.210	-0.161	-0.193	-0.298	0.346	0.065	0.335	0.492	1.000	
	Quality	-0.094	0.155	0.046	-0.287	0.357	-0.163	0.531	0.433	0.875	1.000

5.3.3 Critical Correlation Coefficient Level

The critical correlation level was found to be 0.355, based on *df*=31 for the paired comparison study. All correlations above 0.355 in Table 6 remain and are shown in Table 7. These correlations were then used in the regression analysis.

Table 7: Significant Pearson product moment correlation coefficients for objective and subjective metrics from the paired comparision study.

Pearson Correlation Coefficient		Objective (calculated)					Subjective (from sound jury)				
		Loudness	**Sharpness**	**SFM Pmag**	**Fluctuation**	**Roughness**	*Pitch*	*Duration*	*Loudness*	*Natural*	*Quality*
Objective (calculated)	**Loudness**										
	Sharpness	0.394									
	SFM Pmag	0.622	0.810								
	Fluctuation	0.789		0.540							
	Roughness										
Subjective (from sound jury)	*Pitch*		0.793	0.654	0.371						
	Duration		-0.634				0.804				
	Loudness	0.808		0.548	0.743						
	Natural								0.492		
	Quality					0.357		0.531	0.433	0.875	

5.3.4 ANOVA

An ANOVA was conducted on the normalized results for all of the subjective metrics. A summary of the ANOVA results is provided in Table 8. The p-values for each metric were below 0.01, which proved to a 99% level of certainty that the distributions for each metric did not happen by chance. The F statistic for every sample was above the F_{crit} value. The results implied the jurors were able to discern that all of the flooring composite samples were not simply the same sample played over and over. The p-value and F statistic results proved that the subjective results from the sound jury study were statistically significant.

Table 8: AVOVA results for all normalized subjective metrics from the paired comparison study.

Subjective Sound Jury Metric	P-value	F	F crit (95%)	SS Between Groups	SS Within Groups
Naturalness	< 0.01	3.43	1.48	89.79	867.21
Quality	< 0.01	2.93	1.48	77.85	879.15
Pitch	< 0.01	10.31	1.48	227.35	729.65
Duration	< 0.01	6.19	1.48	150.68	806.32
Loudness	< 0.01	8.53	1.48	196.06	760.94

Additionally, the F statistic from Table 8 is a measure of the ratio of variation between samples and the variation within samples. A higher F statistic value indicated a robust measurement, because the measurement has ample ability to capture the between sample differences and not get lost in the "noise" of within sample variation. Subjective *Pitch*, subjective *Loudness*, and subjective *Duration* were shown to be more capable than subjective *Naturalness* and subjective *Quality*.

5.3.5 Regression Analysis

The ANOVA shows that the sound jury metrics were significant, so the regression analysis can be performed to use objective psychoacoustic metrics to model the subjective sound jury metrics. The correlation coefficients above the critical level can now be used in a regression analysis of the normalized data from the paired comparison experiment. The goal of the regression analysis was to apply appropriate weightings for the influence on significant objective metrics on the subjective metrics. The subjective metrics and their correlated objective metrics used to construct the sound quality index are shown in the lower left quadrant of Table 7. The regression analysis was performed for each subjective metric. No significant correlation exists for the perceived subjective *Naturalness*, so no sound quality index is provided.

5.3.5.1 ***Quality Model***

The index for ***Quality*** is described by the equation

$$Quality = 1.051 - 0.437 \times R$$

where R is the objective **Roughness** metric. The ***Quality*** model is plotted against the subjective *Quality* results from the paired comparison study in Figure 45. The performance of the ***Quality*** model was generally poor. Because there is only one significant factor, the regression model is only a single term linear best fit regression with a correlation coefficient of 0.357. A correlation between 0.25 and 0.5 is generally regarded as weakly correlated [31].

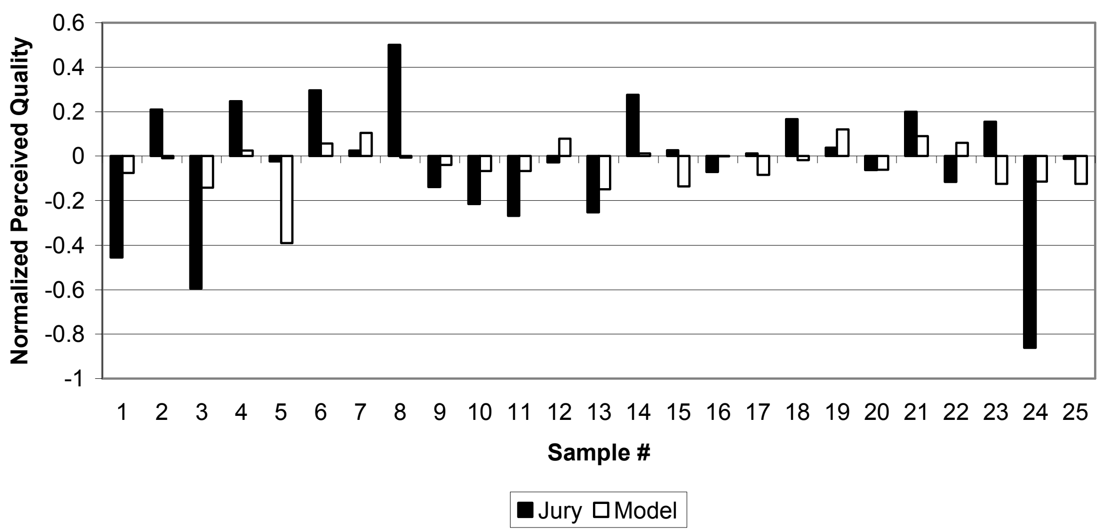

Figure 45: ***Quality*** model compared to the paired comparison subjective *Quality* metric.

5.3.5.2 ***Pitch Model***

The index for the ***Pitch*** is described by the equation

$$Pitch = -9.721 + 3.161 \times S - 2.905 \times SFM + 1.567 \times F$$

where S is the objective **Sharpness** metric, SFM is the objective **Spectral Flatness Measure** metric, and F is the objective **Fluctuation Strength** metric. The ***Pitch*** model is plotted against the actual subjective *Pitch* results from the paired comparison study in Figure 46. The ***Pitch*** model possesses a correlation coefficient of 0.824. A correlation greater than 0.75 is generally regarded as strongly correlated [31].

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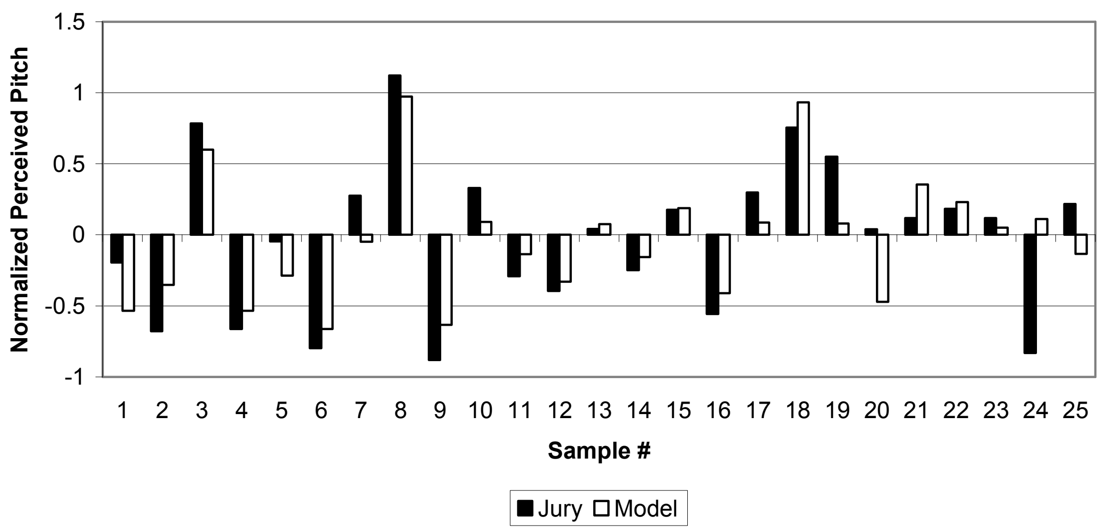


Figure 46: ***Pitch*** model compared to the paired comparison subjective ***Pitch*** metric.

5.3.5.3 ***Duration Model***

The index for the ***Duration*** is described by the equation

$$Duration = 2.717 - 2.039 \times S$$

where S is the objective **Sharpness** metric. The ***Duration*** model is plotted against the actual subjective *Duration* results from the paired comparison study in Figure 47. Because there is only one significant factor, the regression model is only a single term linear best fit regression with a correlation coefficient of 0.665. A correlation between 0.50 and 0.75 is generally regarded as moderately correlated [31].

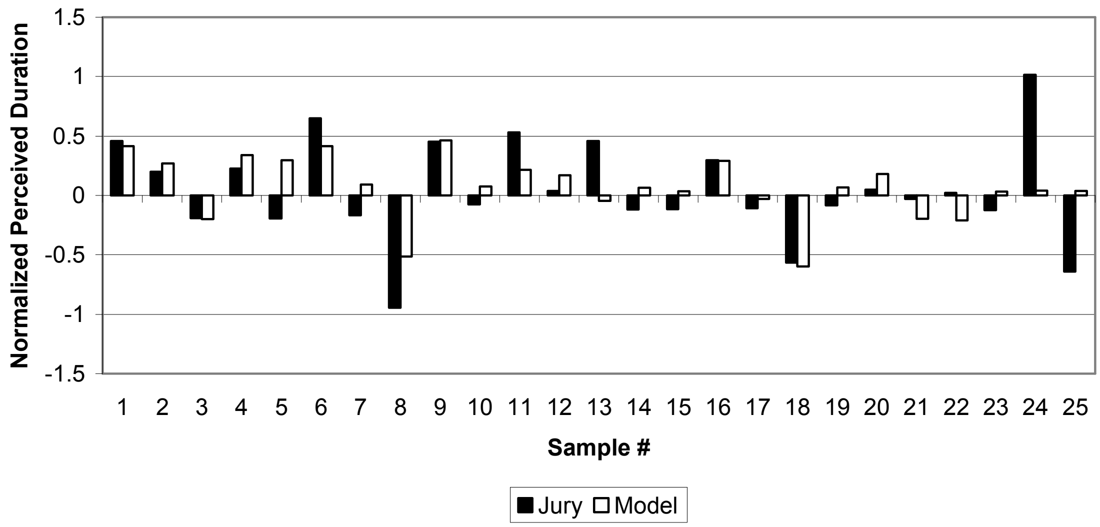


Figure 47: ***Duration*** model compared to the paired comparison subjective *Duration* metric.

5.3.5.4 ***Loudness Model***

The index for the ***Loudness*** is described by the equation

$$Loudness = -7.645 + 0.593 \times N + 3.28 \times SFM + 1.458 \times F$$

where N is the objective **Loudness**, SFM is the objective **Spectral Flatness Measure** metric, and F is the objective **Fluctuation Strength** metric. The ***Loudness*** model is plotted against the subjective *Loudness* results from the paired comparison study in Figure 48. The ***Loudness*** model possesses a correlation coefficient of 0.811. A correlation greater than 0.75 is generally regarded as strongly correlated [31].

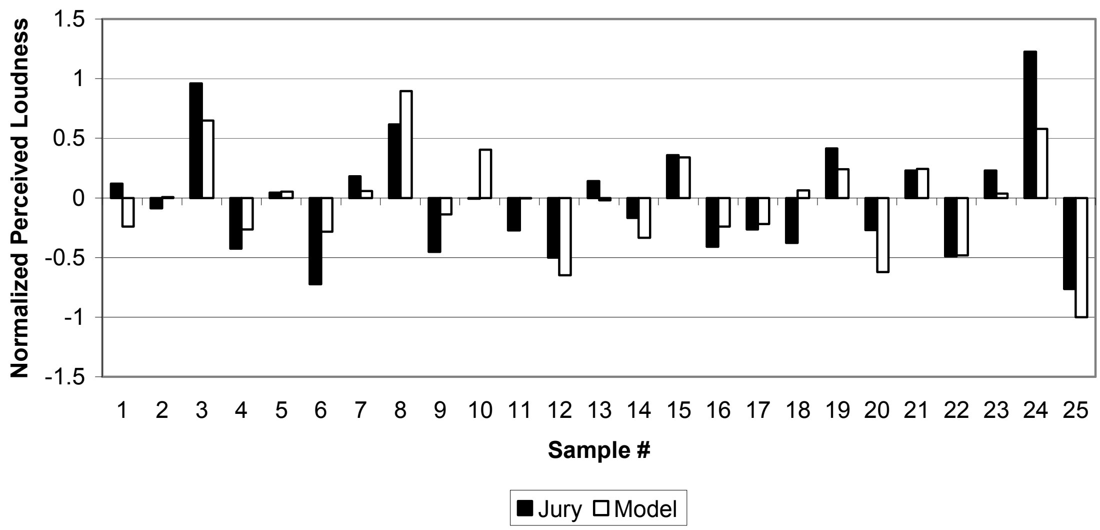


Figure 48: ***Loudness*** model compared to the paired comparison subjective *Loudness* metric.

5.3.6 Factor Analysis

The full results for the factor analysis are provided in Appendix IV. The key points of interest from the factor analysis, the scree plot and the *varimax* rotated factor weightings, are presented in this section.

The results of the scree test allowed the selection the appropriate number of individual factors that could be used for each generic factor. The scree plot from Appendix IV is shown in Figure 49. The number of components that could be used in each generic factor was determined to be between 3 and 4. This number range was determined from the plot and is where the value of the eigenvalues becomes relatively flat. The number of components, shown as the x-axis in Figure 49, is the maximum number of metrics that could be included in each generic factor.

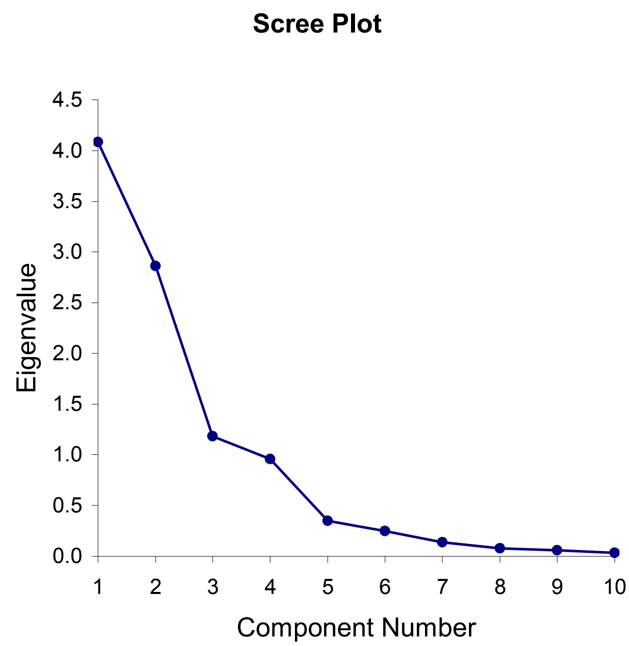


Figure 49: Factor analysis scree plot (taken from Appendix IV).

After the number of components was determined from the scree plot in Figure 49, the number of components could be applied to the generic factors. The summary of the varimax rotated factor weightings is given in Table 9. The point of interest in the *varimax* results is to show the groups of heavily related components. Each factor shown in Table 9 is a generic entity. The components highlighted in Table 9 are the most highly correlated 3 or 4 components in each factor.

Table 9: *Varimax* rotated factor weightings for the calculated objective metrics and the normalized subjective metrics (taken from Appendix IV) with the significant factor correlations in bold.

Varimax Rotated Factor Loadings

	Variable	Factor 1	Factor 2	Factor 3
Objective Metrics	**Loudness**	0.119	-0.017	**0.937**
	Sharpness	**0.844**	0.003	0.333
	SFM Pmag	**0.584**	-0.043	**0.671**
	Fluctuation	0.135	0.209	**0.832**
	Roughness	-0.091	**-0.695**	0.053
Subjective Metrics	*Pitch*	**0.919**	0.055	0.242
	Duration	**-0.908**	0.221	0.105
	Loudness	0.095	**0.336**	**0.857**
	Natural	0.054	**-0.866**	-0.285
	Quality	0.327	**-0.855**	-0.223

The first factor groups the objective **Sharpness**, the objective **Spectral Flatness Measure**, the subjective *Pitch*, and the subjective *Duration*. The second factor groups the objective **Roughness**, the subjective *Naturalness*, and the subjective *Quality*. The third factor groups the objective **Loudness**, the objective **Spectral Flatness Measure**, the objective **Fluctuation Strength**, and the subjective *Loudness*.

Each of the three factors was inspected and assigned a general group name to describe the nature of the relationship. The first factor can be described as generally relating the spectral shape of the impact sound to the subjective *Pitch* and subjective *Duration*. The second factor can be described as relating the objective **Roughness**, or higher frequency modulation, to the subjective *Naturalness* and subjective *Quality* of the impact sound. The third factor relates the objective **Loudness** plus some of the spectral shape metrics to the subjective *Loudness*.

5.3.7 Post-hoc t-test

The t-test was used to show which samples are significantly different than the reference hardwood flooring sample, sample 23. Table 10 shows the specific areas where each sample is found to be different from the reference hardwood as well as the nature of the difference, e.g. more artificial / more artificial.

Table 10: Summary of post-hoc t-tests - all samples that are significantly different ($p<0.05$) marked (X) from the reference hardwood floor.

	Natural		Quality		Pitch		Duration		Loudness	
Sample	Artificial	Natural	Low	High	Dull	Bright	Hollow	Sharp	Soft	Loud
1			X					X		
2					X					
3	X		X			X				X
4					X			X	X	
5										
6					X			X	X	
7										
8						X	X			
9					X			X	X	
10			X							
11						X		X	X	
12					X				X	
13	X		X					X		
14					X				X	
15										
16					X			X	X	
17									X	
18						X		X	X	
19						X				
20									X	
21										
22									X	
23										
24	X		X		X			X		X
25							X		X	

Four samples did not establish any statistically significant differences from the reference hardwood floor sample. Sample 5, 7, 15, and 21 were statistically similar to the reference hardwood floor in all categories. These four samples were the best performers from the sound jury.

Generally, the ability of a sample to be shown statistically different from the reference hardwood floor sample was an indicator of the precision of the metric. The precision of the metric was created from the relative agreement among the sound jury. Metrics with poor jury agreement and resulting high variance were not able to show statistically different performance for many flooring samples.

5.4 Sound Quality Index Summary

The models for ***Quality***, ***Pitch***, ***Duration***, and ***Loudness*** were all shown to be statistically significant to a 95% level of confidence, with the ***Pitch***, ***Duration***, and ***Loudness*** models generally correlating well to the subjective perceptions of subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. The correlation for the ***Quality*** was somewhat lower. While significant, the models did show evidence of weakness. Each model predicted acoustical performance that did not correspond to the subjective results from the sound jury for certain samples.

Despite the inability of the models to consistently predict the performance of the samples based on the perceptive results, the models do provide valuable insight into the underlying factors driving the human perception of desirable acoustical characteristics of flooring. The factor analysis provides primary associations amongst the three factors discussed in Section 5.3.6. Together, the sound quality index models and factor analysis provide information about perceived flooring performance. The models show which calculated psychoacoustic metrics drive the human perception metrics, and the factor analysis factors show which metrics will change when an associated metric is changed.

The t-test determines the performance of each individual sample relative to the reference hardwood floor. The t-test also indicates the precision obtained in the sound jury for each subjective metric.

CHAPTER 6. CONCLUSIONS

6.1 Sound Jury

Two sound jury studies were performed for this thesis. The first study did not produce strong statistical agreement of the sound quality amongst jurors, where samples were consistently perceived as obviously better or worse than others. Based on the results of the first sound jury, a second jury was conducted with a different type of procedure in an effort to produce stronger statistical results. The second study failed to do so, as well. Human testing is generally an imprecise science, with the needed level of statistical correlations varying from one area to another. In this thesis, two distinct levels of correlations occurred amongst jurors in both the semantic differential and paired comparison studies. Lower correlations are observed for “sound quality metrics”, which consist of subjective *Quality* and subjective *Naturalness*, and higher correlations were observed for “acoustical metrics”, which consist of subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. These two types of metrics are discussed.

6.1.1 “Sound quality metrics” versus “Acoustical metrics”

Both the semantic differential study and the paired comparison study showed that much better correlations exist between the objective and subjective results for the metrics subjective *Pitch*, subjective *Duration*, and subjective *Loudness* than the metrics subjective *Quality* and subjective *Naturalness*. The juror was asked to rate their perception of each sample’s subjective *Quality* and subjective *Naturalness* as part of the sound jury study. The low F statistic for subjective *Quality* and subjective *Naturalness* compared to subjective *Pitch*, subjective *Duration*, and subjective *Loudness* indicated that the metrics subjective *Quality* and subjective *Naturalness* were ambiguous compared to subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. Consequently, the F statistic results drove the correlation coefficient results between the subjective and objective metrics. The correlation between subjective *Quality* and subjective *Naturalness* to the objective metrics were much lower than the correlations between subjective *Pitch*, subjective *Duration*, and subjective *Loudness* and the objective metrics. Subjective *Pitch*, subjective *Duration*, and subjective *Loudness* were acoustical traits of the sample, while subjective *Quality* and subjective *Naturalness* were a preference of sound quality.

6.1.1.1 *"Sound quality metrics"*

Part of the analysis of the sound jury study was to determine whether or not there is a unified definition of floor sound quality. This was accomplished though the metrics subjective *Quality* and subjective *Naturalness*. When all external factors were removed from a juror's perception of floor quality, such as visual appearance of the floor and perhaps even knowledge of the floor material, the juror had difficulty picking out a real hardwood floor over most of the laminate composites tested as part of the study. A high variance was observed in these two metrics, as compared to the subjective *Pitch*, subjective *Duration*, and subjective *Loudness* metrics in Table 8. No laminate flooring composite sample tested statistically higher subjective *Quality* or subjective *Naturalness*, but only a few tested as lower subjective *Quality* and subjective *Naturalness*. The inability of the study to show statistically significant results for subjective *Naturalness* showed that there was weak agreement among jurors about what flooring sound quality is.

As discussed in the Theory section of this thesis, sound quality is based on the expected performance of a product based on the previous use of similar products. Each juror's previous experiences were different and may result in different interpretations of sound quality. If there was not a unified perception of sound quality amongst all jurors, then the variance in the subjective *Quality* and subjective *Naturalness* metric will be high.

6.1.1.2 *"Acoustical metrics"*

The juror was asked to rate his perception of specific acoustical aspects of the sound for the metrics subjective *Pitch*, subjective *Duration*, and subjective *Loudness*. Table 8 showed that the jurors had a much higher level of agreement for these three metrics compared to subjective *Quality* and subjective *Naturalness*. The F statistic and correlations for subjective *Pitch*, subjective *Duration*, and subjective *Loudness* was high, indicating that the "acoustical metrics" in the sound jury procedure produced robust results.

6.1.2 Recommendations for Future Work

The inability of jurors to agree upon subjective *Quality* and subjective *Naturalness* sounding floors when removed from all other physical stimuli except the impact sound of the floor itself indicates that benchmarking flooring performance based on subjective *Quality* and subjective *Naturalness* is an imprecise task. It is highly unlikely that a hardwood floor will be statistically proven to be of higher subjective *Quality* and subjective *Naturalness* than many laminate flooring composites, given the lack of agreement among jurors. Instead, efforts are better spent benchmarking the "acoustical metrics" of flooring in future testing.

Improvement to the statistics of the "acoustical metrics" may be possible. For the juror's perception of subjective *Pitch*, subjective *Duration*, and subjective *Loudness*, the sound jury method of magnitude matching may be a method capable of producing more accurate and precise results. As an example, the objective **Loudness** of a laminate flooring composite sample may be adjusted by the juror to match their perception of a reference sample, presumably a reference hardwood floor. The magnitude matching method creates a specific magnitude of shift for each sample. The magnitude matching method has been widely employed in psychoacoustics as a method to obtain the human response to acoustic signals in a very precise manner.

6.2 Sound Quality Index

The sound quality indexes created for each of the sound jury metrics have mixed results. The performance of each index reflects upon the agreement amongst the participants of the sound jury for each respective metric.

6.2.1 Model Performance

The inability of jurors to effectively judge subjective *Naturalness* and subjective *Quality* resulted in poor performance of their sound quality indexes. The shortcomings of the indexes for the "sound quality metrics" were due to the high variability of the sound jury responses for subjective *Quality* and subjective *Naturalness*.

The sound quality indexes for the three acoustical metrics of ***Pitch***, ***Duration***, and ***Loudness*** possessed much better agreement. The sound quality indexes for Pitch and ***Loudness*** both had correlations above 0.8 and the index for ***Duration*** had a correlation of 0.665. The models for ***Pitch***, ***Duration***, and ***Loudness*** possessed good correlations, but the models have discrepancies between the model predictions and the subjective results as well.

For example, the ***Pitch*** of sample 20 and sample 24 from the ***Pitch*** model in Figure 46 were poorly predicted by the model compared to the jury subjective *Pitch*. The reason that the error associated with these two samples is a problem is that their subjective *Pitch* from the sound jury study laid very close to that of the reference hardwood floor, but their score from the ***Pitch*** model scored them as being very different from the reference hardwood floor. From a sample screening standpoint, if samples 20 and 24 were tested in a lab and then processed in the ***Pitch*** model without an actual sound jury to confirm the findings, the model results would have shown that these two samples scored poorly as compared to the reference hardwood floor sample, whereas the sound jury subjective *Pitch* scored them very well.

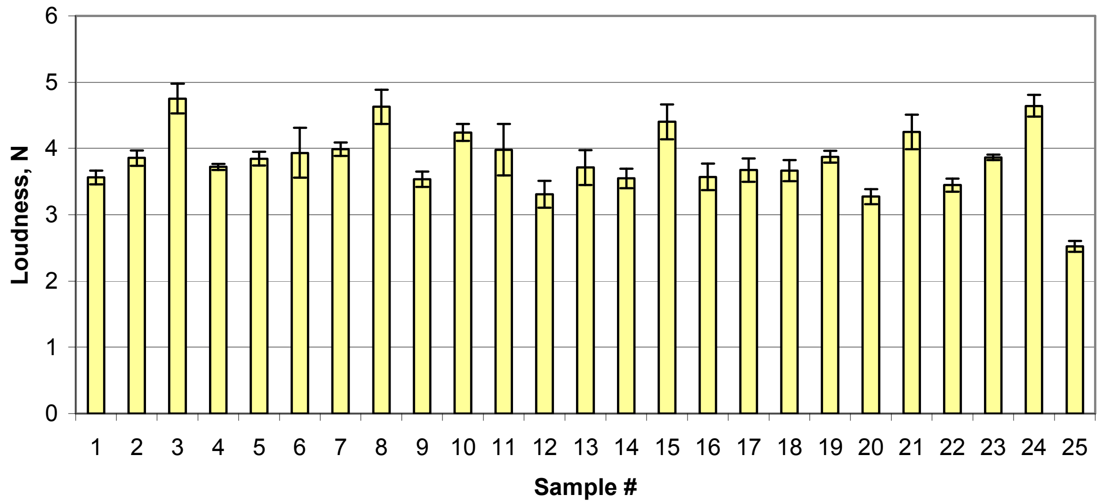
Cleary, the sound quality index models created did not perform perfectly. However, the sound quality indexes for ***Quality***, ***Pitch***, ***Duration***, and ***Loudness*** were all created from significant correlations. Whether or not the performance of the sound quality index models is adequate would need to be collectively agreed upon by industry.

6.2.2 Recommendations for Future Work

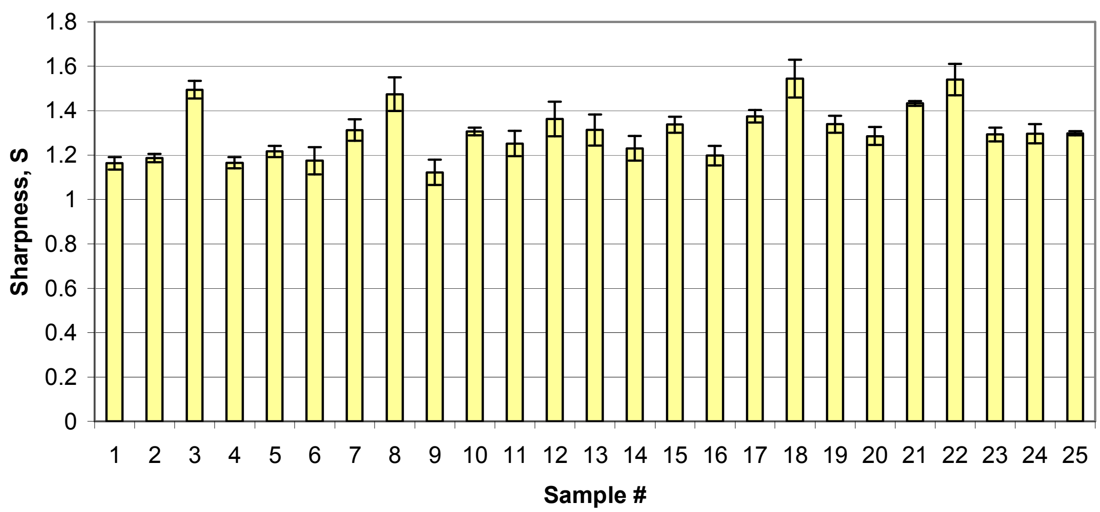
The focus of future work should be to improve the accuracy and precision of the sound jury perceived acoustical metrics subjective *Pitch*, subjective *Duration*, and subjective *Loudness* discussed in Section 6.1.1.2. Improving these three metrics would result in improved sound quality indexes for ***Pitch***, ***Duration***, and ***Loudness*** and a more effective and accurate rating tool.

APPENDICES

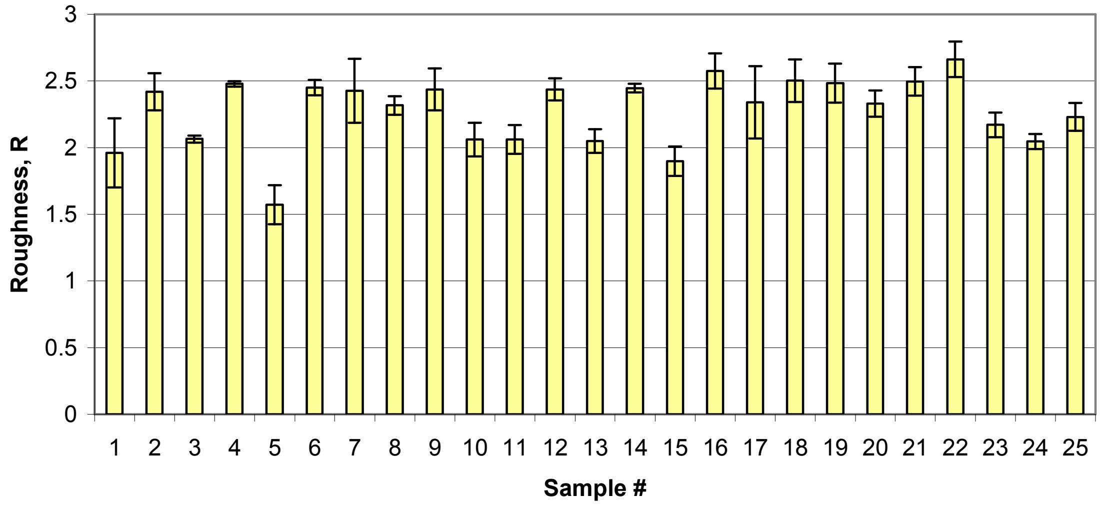
Appendix I: Repeatability of ball drop procedure for calculated psychoacoustic metrics.



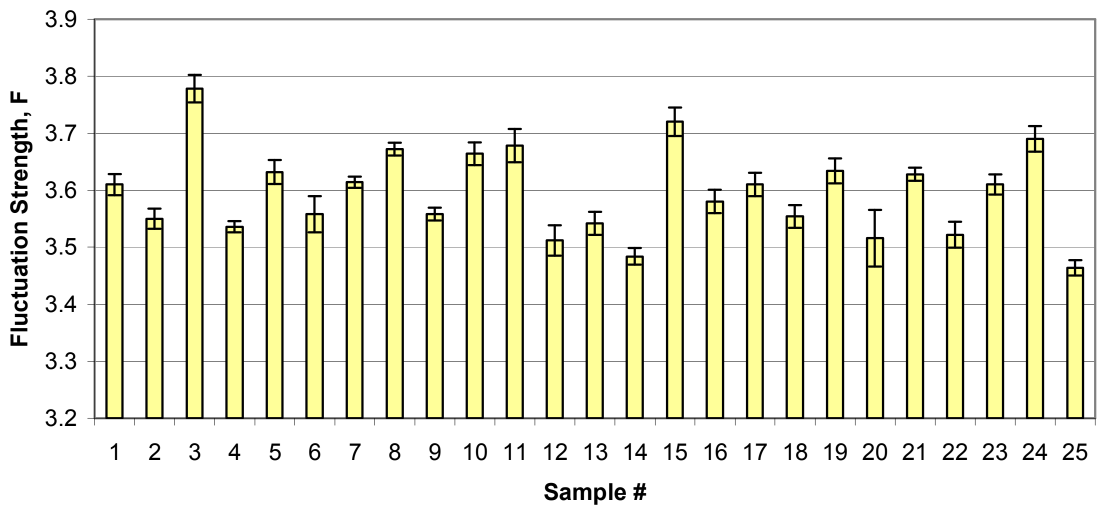
Appendix I-1: Calculated **Loudness** metric for 5 ball impacts for each sample with 95% confidence interval bars.



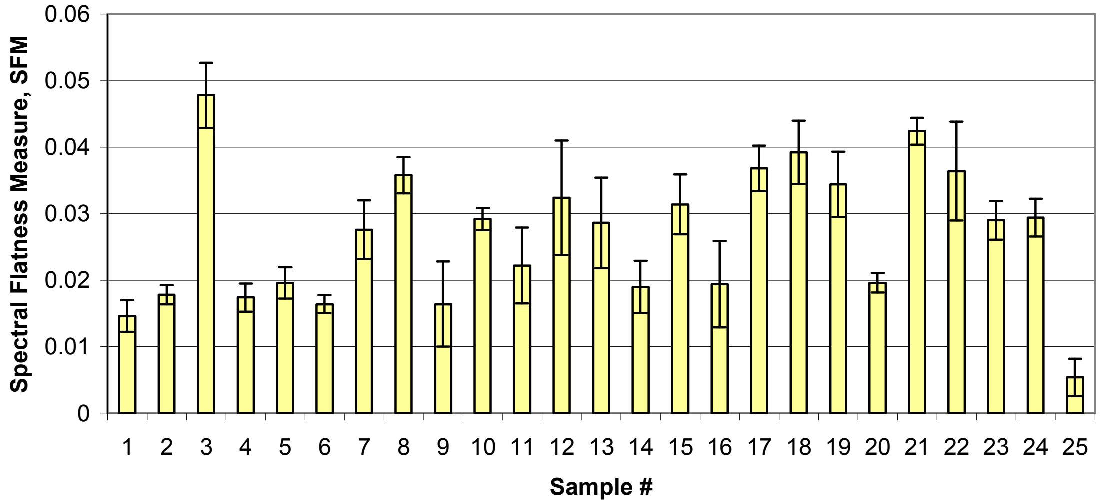
Appendix I-2: Calculated **Sharpness** metric for 5 ball impacts for each sample with 95% confidence interval bars.



Appendix I-3: Calculated **Roughness** metric for 5 ball impacts for each sample with 95% confidence interval bars.



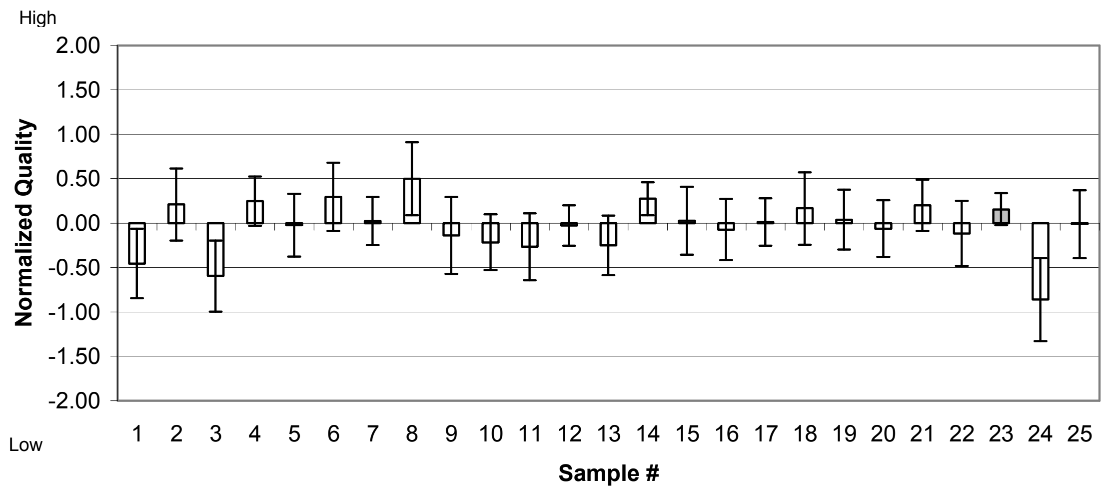
Appendix I-4: Calculated **Fluctuation Strength** metric for 5 ball impacts for each sample with 95% confidence interval bars.



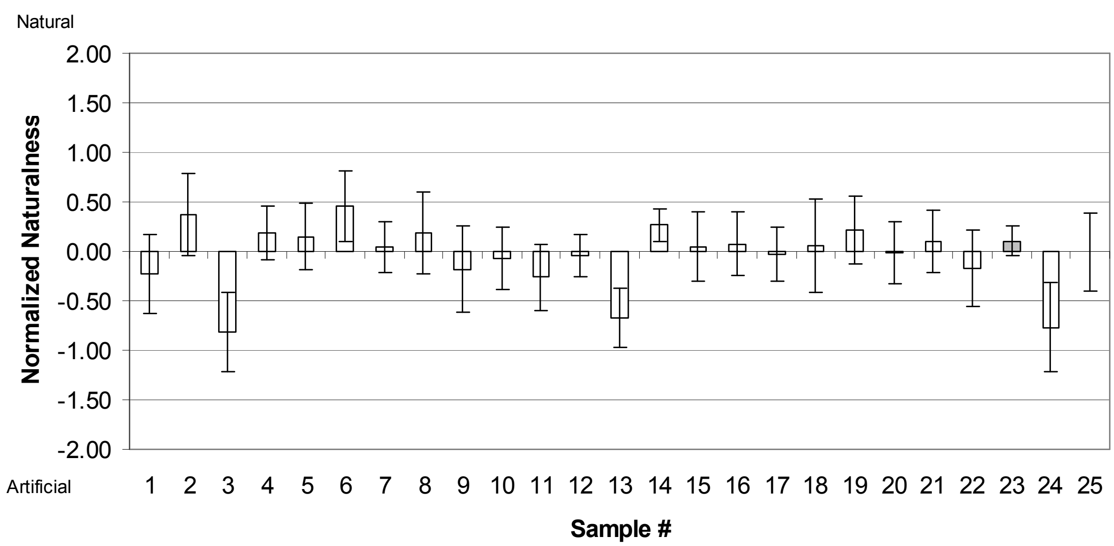
Appendix I-5: Calculated **Spectral Flatness Measure** metric for 5 ball impacts for each sample with 95% confidence interval bars.

Appendix II: Normalized data plots of the subjective metrics from the paired comparison study.

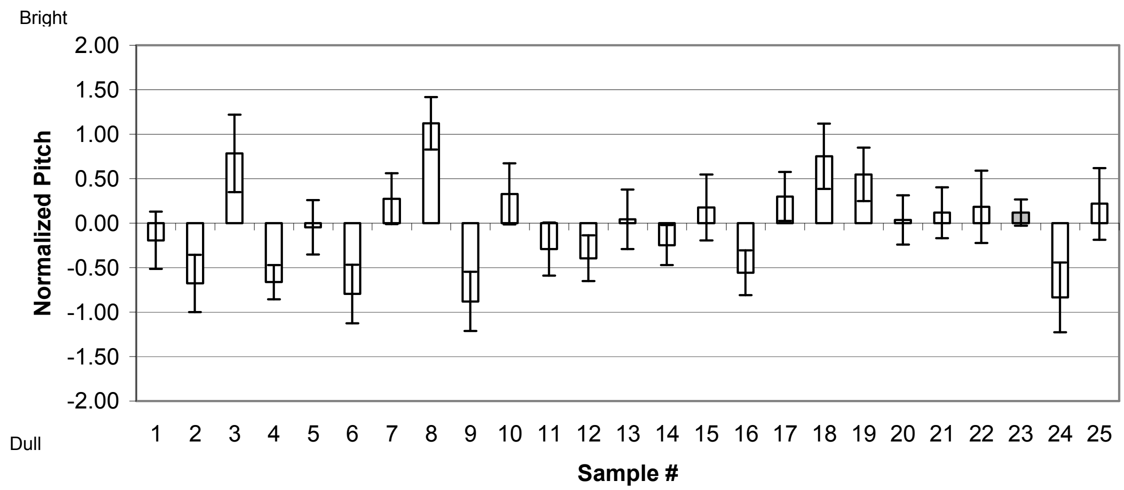
Appendix II-1: Normalized subjective *Quality* from the paired comparison experiment with 95% confidence interval bars.



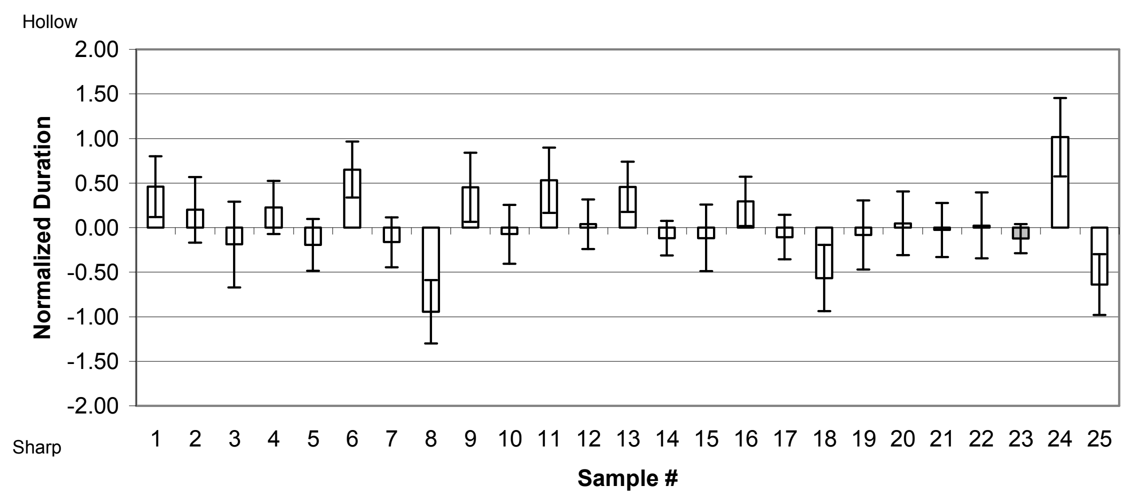
Appendix II-2: Normalized subjective *Naturalness* from the paired comparison experiment with 95% confidence interval bars.



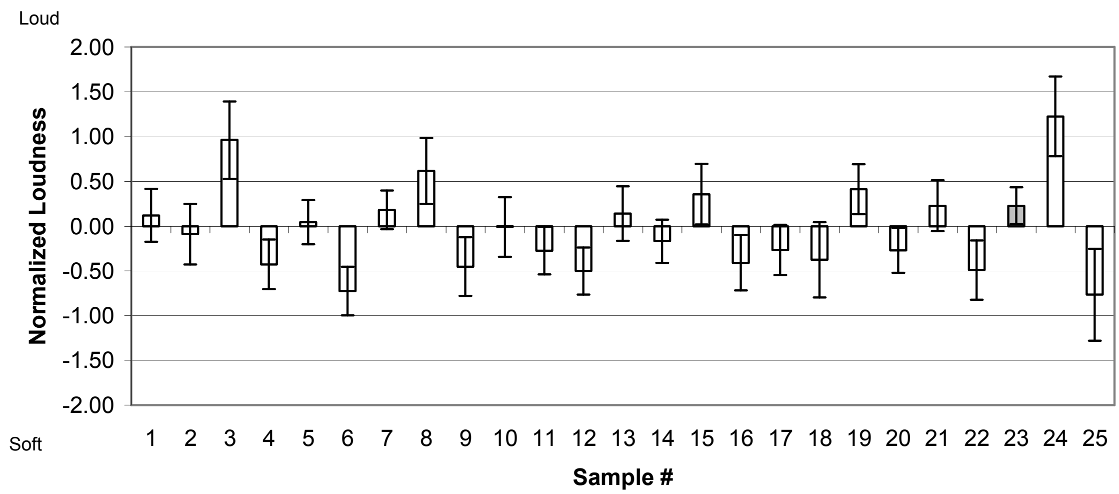
Appendix II-3: Normalized subjective *Pitch* from the paired comparison experiment with 95% confidence interval bars.



Appendix II-4: Normalized subjective *Duration* from the paired comparison experiment with 95% confidence interval bars.



Appendix II-5: Normalized subjective *Loudness* from the paired comparison experiment with 95% confidence interval bars.



Appendix III-1: ANOVA subjective *Naturalness* results for normalized paired comparison experiment.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	33	-7.55333	-0.22889	1.361885
Sample 2	33	12.44554	0.377138	1.467202
Sample 3	33	-26.8382	-0.81328	1.37098
Sample 4	33	6.179491	0.187257	0.63029
Sample 5	33	4.896228	0.148371	0.969804
Sample 6	33	15.16618	0.459581	1.124558
Sample 7	33	1.462649	0.044323	0.586189
Sample 8	33	6.0911	0.184579	1.492092
Sample 9	33	-5.97118	-0.18094	1.633869
Sample 10	33	-2.43889	-0.07391	0.826114
Sample 11	33	-8.65833	-0.26237	0.939757
Sample 12	33	-1.34202	-0.04067	0.412612
Sample 13	33	-22.3278	-0.6766	0.779394
Sample 14	33	8.792209	0.266431	0.23523
Sample 15	33	1.582347	0.04795	1.061715
Sample 16	33	2.570002	0.077879	0.923346
Sample 17	33	-0.85921	-0.02604	0.637953
Sample 18	33	1.955412	0.059255	1.884532
Sample 19	33	7.189358	0.217859	1.013793
Sample 20	33	-0.68762	-0.02084	0.846686
Sample 21	33	3.392408	0.1028	0.857739
Sample 22	33	-5.6549	-0.17136	1.283088
Sample 23	33	3.436914	0.104149	0.202484
Sample 24	33	-25.3205	-0.76729	1.738796
Sample 25	33	-0.2347	-0.00711	1.341471
Sample 26	33	4.394364	0.133163	0.201453
Sample 27	33	3.432217	0.104007	0.483615
Sample 28	33	8.618711	0.261173	0.309484
Sample 29	33	9.739443	0.295135	0.20187
Sample 30	33	6.542118	0.198246	0.282194

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	89.79371	29	3.096335	3.427652	4.38E-09	1.47936
Within Groups	867.2063	960	0.90334			
Total	957	989				

Appendix III-2: ANOVA subjective *Quality* results for normalized paired comparison experiment.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	33	-15.072	-0.45673	1.323384
Sample 2	33	6.91147	0.209438	1.39607
Sample 3	33	-19.6635	-0.59586	1.390082
Sample 4	33	8.140931	0.246695	0.661255
Sample 5	33	-0.80375	-0.02436	1.067722
Sample 6	33	9.757827	0.295692	1.261426
Sample 7	33	0.818552	0.024805	0.634093
Sample 8	33	16.48505	0.499547	1.449966
Sample 9	33	-4.58107	-0.13882	1.627197
Sample 10	33	-7.11533	-0.21562	0.84033
Sample 11	33	-8.84749	-0.26811	1.224014
Sample 12	33	-0.89752	-0.0272	0.442323
Sample 13	33	-8.29983	-0.25151	0.963994
Sample 14	33	9.092576	0.275533	0.294942
Sample 15	33	0.877901	0.026603	1.255947
Sample 16	33	-2.38825	-0.07237	1.018611
Sample 17	33	0.389564	0.011805	0.609579
Sample 18	33	5.47381	0.165873	1.420759
Sample 19	33	1.248416	0.037831	0.975519
Sample 20	33	-2.06789	-0.06266	0.881974
Sample 21	33	6.576586	0.19929	0.716077
Sample 22	33	-3.83436	-0.11619	1.159742
Sample 23	33	5.129224	0.155431	0.277266
Sample 24	33	-28.4273	-0.86143	1.873938
Sample 25	33	-0.40293	-0.01221	1.264739
Sample 26	33	6.032146	0.182792	0.14737
Sample 27	33	2.107208	0.063855	0.548608
Sample 28	33	10.53215	0.319156	0.187891
Sample 29	33	7.313823	0.221631	0.241331
Sample 30	33	5.513938	0.167089	0.317322

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	77.849	29	2.684448	2.931317	4.81E-07	1.47936
Within Groups	879.151	960	0.915782			
Total	957	989				

Appendix III-3: ANOVA subjective *Pitch* results for normalized paired comparison experiment.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sample 1	33	-6.39594	-0.19382	0.880356
Sample 2	33	-22.3625	-0.67765	0.899286
Sample 3	33	25.87346	0.784044	1.636981
Sample 4	33	-21.8805	-0.66305	0.316735
Sample 5	33	-1.54696	-0.04688	0.800248
Sample 6	33	-26.2811	-0.7964	0.940396
Sample 7	33	9.073162	0.274944	0.701003
Sample 8	33	37.06256	1.123108	0.744155
Sample 9	33	-29.0315	-0.87974	0.945735
Sample 10	33	10.81064	0.327595	1.02061
Sample 11	33	-9.65102	-0.29246	0.759995
Sample 12	33	-13.0165	-0.39444	0.563292
Sample 13	33	1.398563	0.042381	0.959777
Sample 14	33	-8.19921	-0.24846	0.435716
Sample 15	33	5.819408	0.176346	1.19148
Sample 16	33	-18.3693	-0.55664	0.548564
Sample 17	33	9.882729	0.299477	0.65307
Sample 18	33	24.86031	0.753343	1.161807
Sample 19	33	18.11185	0.548844	0.777255
Sample 20	33	1.228322	0.037222	0.661444
Sample 21	33	3.900912	0.118209	0.706016
Sample 22	33	6.079068	0.184214	1.428357
Sample 23	33	3.908086	0.118427	0.183301
Sample 24	33	-27.4847	-0.83287	1.32208
Sample 25	33	7.168566	0.217229	1.39323
Sample 26	33	5.030567	0.152441	0.247936
Sample 27	33	5.780179	0.175157	0.221409
Sample 28	33	2.156901	0.065361	0.240523
Sample 29	33	3.384601	0.102564	0.286416
Sample 30	33	2.689344	0.081495	0.174411

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups		29	7.839632	10.31459	9.82E-40	1.47936
Within Groups		960	0.760053			
Total	957	989				

Appendix III-4: ANOVA subjective *Duration* results for normalized paired comparison experiment.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample 1	33	15.17034	0.459707	0.997776
Sample 2	33	6.577688	0.199324	1.169565
Sample 3	33	-6.27549	-0.19017	1.994433
Sample 4	33	7.485995	0.226848	0.760708
Sample 5	33	-6.46586	-0.19594	0.725155
Sample 6	33	21.40277	0.648569	0.849048
Sample 7	33	-5.46567	-0.16563	0.681611
Sample 8	33	-31.2322	-0.94643	1.090813
Sample 9	33	14.92733	0.452343	1.289801
Sample 10	33	-2.49937	-0.07574	0.936287
Sample 11	33	17.49322	0.530098	1.152585
Sample 12	33	1.255132	0.038034	0.66917
Sample 13	33	15.07377	0.456781	0.685947
Sample 14	33	-3.92789	-0.11903	0.323092
Sample 15	33	-3.8682	-0.11722	1.19921
Sample 16	33	9.689482	0.293621	0.664404
Sample 17	33	-3.56183	-0.10793	0.534207
Sample 18	33	-18.6848	-0.56621	1.179063
Sample 19	33	-2.77331	-0.08404	1.29069
Sample 20	33	1.541175	0.046702	1.102259
Sample 21	33	-0.94992	-0.02879	0.790103
Sample 22	33	0.743273	0.022523	1.18073
Sample 23	33	-4.10942	-0.12453	0.226656
Sample 24	33	33.47177	1.014296	1.671425
Sample 25	33	-21.1629	-0.6413	1.005283
Sample 26	33	-4.83068	-0.14638	0.259006
Sample 27	33	-8.59285	-0.26039	0.202308
Sample 28	33	-8.94226	-0.27098	0.200026
Sample 29	33	-7.82714	-0.23719	0.216731
Sample 30	33	-3.66217	-0.11097	0.1494

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups		29	5.195873	6.186179	2.74E-21	1.47936
Within Groups		960	0.839916			
Total	957	989				

Appendix III-5: ANOVA subjective *Loudness* results for normalized paired comparison experiment.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Sample 1	33	3.971207	0.12034	0.74159
Sample 2	33	-2.95235	-0.08947	0.978987
Sample 3	33	31.71661	0.961109	1.623561
Sample 4	33	-14.0926	-0.42705	0.665099
Sample 5	33	1.47498	0.044696	0.5272
Sample 6	33	-23.9387	-0.72542	0.644946
Sample 7	33	5.965026	0.180758	0.399985
Sample 8	33	20.37177	0.617327	1.160075
Sample 9	33	-14.9342	-0.45255	0.916223
Sample 10	33	-0.28344	-0.00859	0.947921
Sample 11	33	-8.98825	-0.27237	0.60661
Sample 12	33	-16.5404	-0.50122	0.594446
Sample 13	33	4.662256	0.14128	0.797661
Sample 14	33	-5.54867	-0.16814	0.503313
Sample 15	33	11.80875	0.357841	0.978702
Sample 16	33	-13.5258	-0.40987	0.819667
Sample 17	33	-8.80728	-0.26689	0.6802
Sample 18	33	-12.4294	-0.37665	1.524962
Sample 19	33	13.5988	0.412085	0.667607
Sample 20	33	-8.92734	-0.27053	0.54476
Sample 21	33	7.534946	0.228332	0.70187
Sample 22	33	-16.1756	-0.49017	0.946452
Sample 23	33	7.541016	0.228516	0.367279
Sample 24	33	40.46637	1.226254	1.701956
Sample 25	33	-25.2405	-0.76486	2.27057
Sample 26	33	4.604777	0.139539	0.310399
Sample 27	33	3.474674	0.105293	0.24488
Sample 28	33	3.962012	0.120061	0.504107
Sample 29	33	7.018742	0.212689	0.22045
Sample 30	33	4.212625	0.127655	0.188037

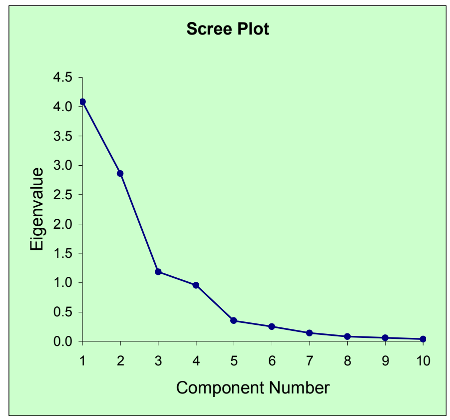
ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups		29	6.760534	8.529023	7.71E-32	1.47936
Within Groups		960	0.792651			
Total	957	989				

Appendix IV: Factor analysis for normalized paired comparison data.

	Loudness	Sharpness	SFM Pmag	Fluctuation	Roughness	Pitch	Duration	Loudness	Natural	Quality
Sample 1	3.523	1.13	0.015	3.61	2.23	-0.193816	0.4597074	0.1203396	-0.228889	-0.456726
Sample 2	3.971	1.201	0.018	3.59	2.38	-0.677652	0.1993239	-0.089465	0.3771377	0.2094385
Sample 3	4.5	1.431	0.038	3.77	2.08	0.7840443	-0.190166	0.9611093	-0.813279	-0.595864
Sample 4	3.647	1.166	0.016	3.54	2.46	-0.663045	0.2268483	-0.42705	0.1872573	0.2466949
Sample 5	3.869	1.187	0.019	3.66	1.51	-0.046878	-0.195935	0.0446964	0.1483705	-0.024356
Sample 6	3.64	1.13	0.016	3.53	2.53	-0.796398	0.6485689	-0.725417	0.4595812	0.2956917
Sample 7	3.949	1.288	0.025	3.62	2.64	0.2749443	-0.165626	0.1807584	0.0443227	0.0248046
Sample 8	5.088	1.585	0.039	3.7	2.39	1.1231079	-0.946431	0.6173265	0.1845788	0.4995471
Sample 9	3.714	1.105	0.016	3.6	2.31	-0.879743	0.4523432	-0.452551	-0.180945	-0.13882
Sample 10	4.318	1.295	0.028	3.7	2.25	0.3275952	-0.075739	-0.008589	-0.073906	-0.215616
Sample 11	3.724	1.226	0.02	3.68	2.25	-0.292455	0.5300975	-0.272371	-0.262374	-0.268106
Sample 12	3.046	1.25	0.021	3.51	2.58	-0.394439	0.0380343	-0.501224	-0.040667	-0.027197
Sample 13	3.924	1.355	0.028	3.57	2.06	0.0423807	0.4567809	0.1412805	-0.6766	-0.25151
Sample 14	3.602	1.301	0.017	3.51	2.43	-0.248461	-0.119027	-0.168142	0.2664306	0.2755326
Sample 15	4.113	1.315	0.032	3.73	2.09	0.1763457	-0.117218	0.3578408	0.0479499	0.0266031
Sample 16	3.618	1.19	0.016	3.57	2.4	-0.556644	0.2936207	-0.409873	0.0778789	-0.072371
Sample 17	3.493	1.347	0.032	3.6	2.21	0.2994766	-0.107934	-0.266887	-0.026037	0.011805
Sample 18	3.899	1.626	0.044	3.6	2.36	0.7533427	-0.566206	-0.376647	0.0592549	0.165873
Sample 19	4.05	1.3	0.031	3.69	2.68	0.5488441	-0.08404	0.4120848	0.2178593	0.0378308
Sample 20	3.299	1.244	0.02	3.43	2.26	0.0372219	0.0467023	-0.270525	-0.020837	-0.062663
Sample 21	4.118	1.43	0.046	3.63	2.61	0.1182095	-0.028785	0.2283317	0.1028002	0.1992905
Sample 22	3.287	1.435	0.029	3.51	2.54	0.1842142	0.0225234	-0.490171	-0.171361	-0.116193
Sample 23	3.823	1.316	0.032	3.64	2.12	0.1184269	-0.124528	0.2285156	0.1041489	0.155431
Sample 24	4.658	1.313	0.029	3.68	2.14	-0.83287	1.0142961	1.2262536	-0.767288	-0.861433
Sample 25	2.609	1.314	0.007	3.48	2.12	0.2172293	-0.641299	-0.764862	-0.007112	-0.01221

Factor Analysis Results for:
Variable Range = Data Reduced (2)!$A$1:$K$26
Factors were extracted by the Principal Component method
from the correlation matrix
All factors with eigenvalues > 1 were extracted



Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	N
Loudness	3.819	0.512	0.102	25
Sharpness	1.299	0.130	0.026	25
SFM Pmag	0.025	0.010	0.002	25
Fluctuation	3.606	0.084	0.017	25
Roughness	2.305	0.250	0.050	25
Pitch	-0.023	0.532	0.106	25
Duration	0.041	0.423	0.085	25
Loudness	-0.028	0.492	0.098	25
Natural	-0.040	0.320	0.064	25
Quality	-0.038	0.296	0.059	25

Correlation Matrix

	Loudness	Sharpness	SFM Pmag	Fluctuation	Roughness	Pitch	Duration	Loudness	Natural	Quality
Loudness	1.000	0.394	0.622	0.789	-0.081	-0.315	0.049	-0.808	-0.210	-0.094
Sharpness	0.394	1.000	0.810	0.251	0.089	-0.793	0.634	-0.330	-0.161	0.155
SFM Pmag	0.622	0.810	1.000	0.540	0.106	-0.654	0.348	-0.548	-0.193	0.046
Fluctuation	0.789	0.251	0.540	1.000	-0.268	-0.371	0.077	-0.743	-0.298	-0.287
Roughness	-0.081	0.089	0.106	-0.268	1.000	0.045	-0.021	0.223	0.346	0.357
Pitch	-0.315	-0.793	-0.654	-0.371	0.045	1.000	-0.804	0.321	0.065	-0.163
Duration	0.049	0.634	0.348	0.077	-0.021	-0.804	1.000	0.026	0.335	0.531
Loudness	-0.808	-0.330	-0.548	-0.743	0.223	0.321	0.026	1.000	0.492	0.433
Natural	-0.210	-0.161	-0.193	-0.298	0.346	0.065	0.335	0.492	1.000	0.875
Quality	-0.094	0.155	0.046	-0.287	0.357	-0.163	0.531	0.433	0.875	1.000

Explained Variance (Eigenvalues)

Value	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8	Factor 9	Factor 10
Eigenvalue	4.084	2.861	1.184	0.956	0.350	0.250	0.140	0.080	0.060	0.036
% of Var.	40.839	28.609	11.839	9.559	3.497	2.502	1.395	0.799	0.600	0.361
Cum. %	40.839	69.448	81.287	90.846	94.342	96.844	98.240	99.039	99.639	100.000

Communalities

	Variable
Loudness	0.893
Sharpness	0.823
SFM Pmag	0.794
Fluctuation	0.755
Roughness	0.494
Pitch	0.906
Duration	0.884
Loudness	0.857
Natural	0.835
Quality	0.888

Unrotated Factor Loadings

Variable	Factor 1	Factor 2	Factor 3
Loudness	0.795	0.169	0.482
Sharpness	0.751	-0.457	-0.224
SFM Pmag	0.853	-0.227	0.124
Fluctuation	0.776	0.289	0.264
Roughness	-0.174	-0.415	0.539
Pitch	0.736	-0.495	-0.346
Duration	-0.395	0.778	0.351
Loudness	0.801	0.412	0.212
Natural	-0.394	-0.724	0.394
Quality	-0.183	-0.878	0.289

Varimax Rotated Factor Loadings

Variable	Factor 1	Factor 2	Factor 3
Loudness	0.119	-0.017	0.937
Sharpness	0.844	0.003	0.333
SFM Pmag	0.584	-0.043	0.671
Fluctuation	0.135	0.209	0.832
Roughness	-0.091	-0.695	0.053
Pitch	0.919	0.055	0.242
Duration	-0.908	0.221	0.105
Loudness	0.095	0.336	0.857
Natural	0.054	-0.866	-0.285
Quality	0.327	-0.855	-0.223

Rotation completed in 6 iterations
Rotation was normalised

Casewise Factor Scores

Case	Factor 1	Factor 2	Factor 3
Sample 1	-0.967	0.982	-0.243
Sample 2	-0.984	-1.195	0.157
Sample 3	0.949	2.031	1.451
Sample 4	-0.955	-1.006	-0.468
Sample 5	0.244	1.037	-0.494
Sample 6	-1.532	-1.633	-0.411
Sample 7	0.082	-0.717	0.407
Sample 8	2.043	-1.270	1.543
Sample 9	-1.426	0.101	-0.277
Sample 10	0.176	0.217	0.639
Sample 11	-0.829	0.598	0.087
Sample 12	-0.259	-0.249	-1.059
Sample 13	0.025	1.509	-0.018
Sample 14	-0.030	-0.890	-0.646
Sample 15	0.307	0.034	0.803
Sample 16	-0.911	-0.312	-0.440
Sample 17	0.723	0.232	-0.453
Sample 18	2.080	-0.328	-0.089
Sample 19	0.139	-1.069	1.042
Sample 20	0.150	0.358	-1.320
Sample 21	0.432	-1.182	1.088
Sample 22	0.645	0.168	-0.851
Sample 23	0.428	-0.139	0.221
Sample 24	-1.703	1.795	1.962
Sample 25	1.173	0.928	-2.630

Appendix V-1: Regression analysis for ***Quality***.

Linear Regression Results for:
Y = Quality Regression!$C$1:$C$25
X = Quality Regression!$B$1:$B$25

Descriptive Statistics

Variable	Mean	Std Dev.	N
Quality	-0.039	0.303	24
Roughness	2.313	0.252	24

Pearson Correlations

	Quality	Roughness
Quality	1.000	0.365
Roughness	0.365	1.000

Significance for Pearson Correlations

	Quality	Roughness
Quality	-	0.080
Roughness	0.080	-

Summary

R^2	R	Adj. R^2	S.E. of Estimate
0.133	0.365	0.094	0.288

ANOVA

Source	Sum Sq.	D.F.	Mean Sq.	F	Prob.
Regression	0.280	1	0.280	3.375	0.080
Residual	1.826	22	0.083		
Total	2.106	23			

Regression Coefficients

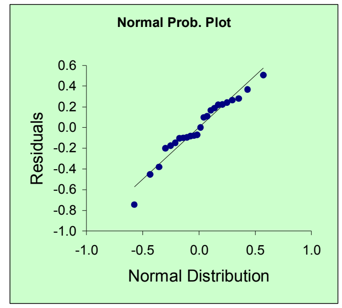
Source	Coefficient	Std Error	Std Beta	-95% C.I.	+95% C.I.	t	Prob.
Intercept	-1.051	0.554		-2.200	0.098	-1.898	0.071
Roughness	0.437	0.238	0.365	-0.056	0.931	1.837	0.080

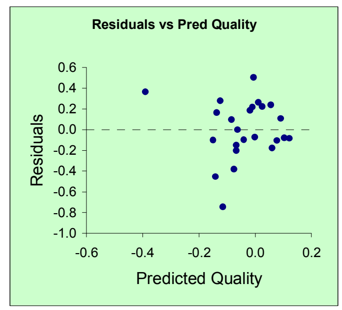
Residuals

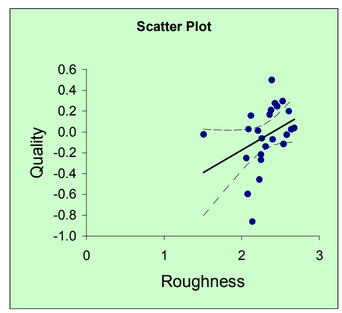
Pred Y	Std Pred Y	Residual	Pred Norm Res	Std Residual	Stu. Residual
-0.076	-0.329	-0.381	-0.354	-1.355	-1.383
-0.010	0.266	0.219	0.172	0.779	0.772
-0.141	-0.923	-0.455	-0.432	-1.645	-1.716
0.025	0.583	0.222	0.209	0.792	0.785
-0.390	-3.183	0.366	0.432	1.766	1.863
0.056	0.861	0.240	0.250	0.866	0.861
0.104	1.297	-0.079	-0.044	-0.292	-0.285
-0.006	0.306	0.505	0.574	1.795	1.898
-0.041	-0.012	-0.098	-0.105	-0.349	-0.341
-0.067	-0.249	-0.149	-0.209	-0.529	-0.520
-0.067	-0.249	-0.201	-0.297	-0.715	-0.707
0.078	1.059	-0.105	-0.172	-0.381	-0.374
-0.150	-1.003	-0.102	-0.138	-0.369	-0.361
0.012	0.464	0.264	0.297	0.939	0.937
-0.137	-0.884	0.163	0.105	0.590	0.581
-0.001	0.345	-0.071	-0.015	-0.253	-0.248
-0.084	-0.408	0.096	0.044	0.342	0.335
-0.019	0.187	0.185	0.138	0.655	0.646
0.121	1.455	-0.083	-0.074	-0.311	-0.305
-0.062	-0.210	0.000	0.015	-0.001	-0.001
0.091	1.178	0.109	0.074	0.398	0.390
0.060	0.900	-0.176	-0.250	-0.637	-0.628
-0.124	-0.765	0.279	0.354	1.003	1.003
-0.115	-0.685	-0.747	-0.574	-2.676	-3.183

1 Case Critical Value for Studentised Residual (alpha = 0.05) 2.080
All Cases Critical Value for Studentised Residual (alpha = 0.05) 3.510

No partials were calculated as only a single x variable was included in the final equation.







Appendix V-2: Regression analysis for ***Pitch***.

Linear Regression Results for:
Y = Pitch Regression!$E$1:$E$25
X = Pitch Regression!$B$1:$D$25
Independent variable entry method: Enter All

Descriptive Statistics

Variable	Mean	Std Dev.	N
Pitch	0.033	0.541	24
Sharpness	1.299	0.133	24
SFM Pmag	0.026	0.009	24
Fluctuation	3.611	0.082	24

Pearson Correlations

	Pitch	Sharpness	SFM Pmag	Fluctuation
Pitch	1.000	-0.795	-0.751	-0.424
Sharpness	-0.795	1.000	0.888	0.272
SFM Pmag	-0.751	0.888	1.000	0.479
Fluctuation	-0.424	0.272	0.479	1.000

Significance for Pearson Correlations

	Pitch	Sharpness	SFM Pmag	Fluctuation
Pitch	-	0.000	0.000	0.039
Sharpness	0.000	-	0.000	0.199
SFM Pmag	0.000	0.000	-	0.018
Fluctuation	0.039	0.199	0.018	-

Summary

R^2	R	Adj. R^2	S.E. of Estimate
0.679	0.824	0.631	0.329

ANOVA

Source	Sum Sq.	D.F.	Mean Sq.	F	Prob.
Regression	4.575	3	1.525	14.088	0.000
Residual	2.165	20	0.108		
Total	6.741	23			

Regression Coefficients

Source	Coefficient	Std Error	Std Beta	-95% C.I.	+95% C.I.	t	Prob.
Intercept	9.721	4.211		0.938	18.505	2.309	0.032
Sharpness	-3.161	1.214	-0.775	-5.694	-0.628	-2.603	0.017
SFM Pmag	2.905	18.910	0.050	-36.541	42.351	0.154	0.879
Fluctuation	-1.567	1.033	-0.237	-3.721	0.587	-1.518	0.145

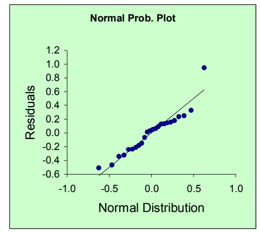
Residuals

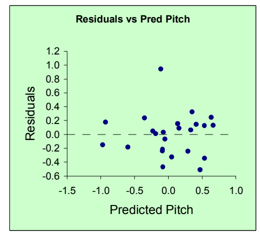
Pred Y	Std Pred Y	Residual	Pred Norm Res	Std Residual	Stu. Residual
0.536	1.127	-0.342	-0.386	-1.109	-1.116
0.351	0.713	0.326	0.471	1.033	1.034
-0.600	-1.419	-0.184	-0.150	-0.633	-0.623
0.534	1.124	0.129	0.115	0.413	0.404
0.289	0.573	-0.242	-0.272	-0.783	-0.775
0.664	1.414	0.133	0.150	0.435	0.426
0.050	0.037	-0.325	-0.324	-1.009	-1.010
-0.974	-2.258	-0.149	-0.115	-0.578	-0.568
0.633	1.345	0.247	0.386	0.810	0.802
-0.089	-0.274	-0.238	-0.228	-0.763	-0.755
0.137	0.233	0.155	0.228	0.513	0.504
0.330	0.667	0.064	0.048	0.206	0.201
-0.075	-0.243	0.033	-0.016	0.103	0.101
0.158	0.279	0.091	0.081	0.318	0.311
-0.188	-0.495	0.011	-0.048	0.038	0.037
0.412	0.848	0.145	0.187	0.464	0.455
-0.085	-0.265	-0.214	-0.187	-0.682	-0.673
-0.932	-2.164	0.179	0.272	0.668	0.659
-0.081	-0.255	-0.468	-0.471	-1.504	-1.557
0.472	0.984	-0.509	-0.625	-1.817	-1.938
-0.354	-0.868	0.236	0.324	1.057	1.061
-0.231	-0.592	0.047	0.016	0.160	0.156
-0.050	-0.186	-0.068	-0.081	-0.219	-0.214
-0.112	-0.325	0.945	0.625	2.982	3.901

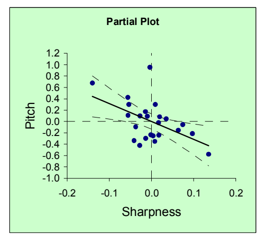
1 Case Critical Value for Studentised Residual (alpha = 0.05) 2.093
All Cases Critical Value for Studentised Residual (alpha = 0.05) 3.561

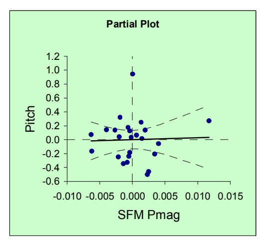
Partials

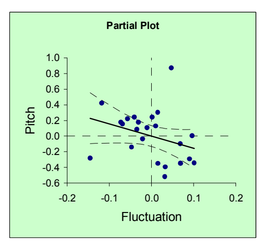
Y adj to Sharpness	Y adj to SFM Pmag	Y adj to Fluctuation	Adj Sharpness	Adj SFM Pmag	Adj Fluctuation
-0.299	-0.346	-0.393	-0.014	-0.001	0.033
0.298	0.321	0.303	0.009	-0.002	0.015
-0.241	-0.185	-0.343	0.018	0.000	0.101
0.173	0.127	0.177	-0.014	0.000	-0.031
-0.253	-0.248	-0.350	0.004	-0.002	0.069
0.301	0.138	0.222	-0.053	0.002	-0.057
-0.350	-0.327	-0.348	0.008	-0.001	0.015
-0.577	-0.167	-0.290	0.135	-0.006	0.090
0.423	0.250	0.244	-0.056	0.001	0.002
-0.235	-0.240	-0.346	-0.001	-0.001	0.069
0.044	0.144	0.004	0.035	-0.004	0.097
0.095	0.066	0.178	-0.010	0.001	-0.073
-0.021	0.032	0.087	0.017	0.000	-0.034
-0.216	0.073	0.107	0.097	-0.006	-0.011
0.098	0.016	-0.096	-0.027	0.001	0.068
0.083	0.137	0.130	0.020	-0.003	0.010
-0.096	-0.204	-0.140	-0.037	0.003	-0.047
-0.055	0.177	0.243	0.074	-0.001	-0.041
-0.338	-0.461	-0.518	-0.041	0.002	0.032
-0.422	-0.502	-0.281	-0.028	0.002	-0.145
0.679	0.270	0.420	-0.140	0.012	-0.118
-0.154	0.041	0.154	0.064	-0.002	-0.069
0.106	-0.057	-0.035	-0.055	0.004	-0.021
0.956	0.945	0.871	-0.004	0.000	0.047











Appendix V-3: Regression analysis for ***Duration***.

Linear Regression Results for:
Y = Duration Regression!$C$1:$C$25
X = Duration Regression!$B$1:$B$25

Descriptive Statistics

Variable	Mean	Std Dev.	N
Duration	-0.069	0.407	24
Sharpness	1.299	0.133	24

Pearson Correlations

	Duration	Sharpness
Duration	1.000	0.665
Sharpness	0.665	1.000

Significance for Pearson Correlations

	Duration	Sharpness
Duration	-	0.000
Sharpness	0.000	-

Summary

R^2	R	Adj. R^2	S.E. of Estimate
0.443	0.665	0.417	0.311

ANOVA

Source	Sum Sq.	D.F.	Mean Sq.	F	Prob.
Regression	1.685	1	1.685	17.465	0.000
Residual	2.123	22	0.096		
Total	3.808	23			

Regression Coefficients

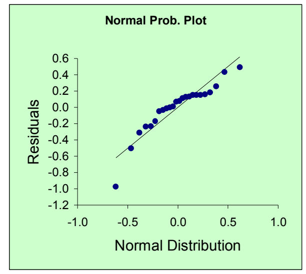
Source	Coefficient	Std Error	Std Beta	-95% C.I.	+95% C.I.	t	Prob.
Intercept	-2.717	0.637		-4.038	-1.397	-4.267	0.000
Sharpness	2.039	0.488	0.665	1.027	3.051	4.179	0.000

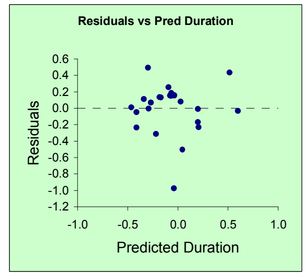
Residuals

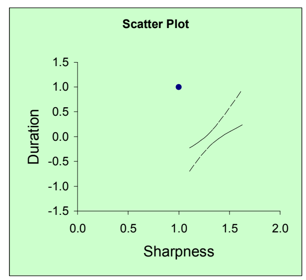
Pred Y	Std Pred Y	Residual	Pred Norm Res	Std Residual	Stu. Residual
-0.413	-1.270	-0.047	-0.185	-0.159	-0.155
-0.268	-0.735	0.069	-0.016	0.230	0.225
0.201	0.997	-0.010	-0.114	-0.035	-0.034
-0.340	-0.999	0.113	0.048	0.380	0.373
-0.297	-0.841	0.493	0.619	1.648	1.719
-0.413	-1.270	-0.235	-0.320	-0.804	-0.797
-0.091	-0.080	0.257	0.382	0.844	0.839
0.515	2.157	0.432	0.466	1.599	1.662
-0.464	-1.458	0.012	-0.048	0.041	0.040
-0.077	-0.027	0.153	0.185	0.502	0.493
-0.217	-0.547	-0.313	-0.382	-1.035	-1.037
-0.169	-0.366	0.130	0.080	0.430	0.422
0.046	0.425	-0.502	-0.466	-1.659	-1.733
-0.065	0.018	0.184	0.320	0.604	0.595
-0.036	0.124	0.153	0.225	0.504	0.495
-0.291	-0.818	-0.003	-0.080	-0.009	-0.009
0.029	0.365	0.079	0.016	0.260	0.254
0.598	2.466	-0.032	-0.148	-0.123	-0.120
-0.067	0.011	0.151	0.148	0.495	0.487
-0.181	-0.411	0.134	0.114	0.443	0.434
0.198	0.990	-0.170	-0.225	-0.571	-0.562
0.209	1.028	-0.231	-0.270	-0.779	-0.772
-0.034	0.131	0.158	0.270	0.521	0.513
-0.040	0.109	-0.974	-0.619	-3.205	-4.288

1 Case Critical Value for Studentised Residual (alpha = 0.05) 2.080
All Cases Critical Value for Studentised Residual (alpha = 0.05) 3.510

No partials were calculated as only a single x variable was included in the final equation.







Appendix V-4: Regression analysis for ***Loudness***.

Linear Regression Results for:
Y = Loudness Regression!$E$1:$E$25
X = Loudness Regression!$B$1:$D$25
Independent variable entry method: Enter All

Descriptive Statistics

Variable	Mean	Std Dev.	N
Loudness	-0.002	0.478	24
Loudness	3.870	0.455	24
SFM Pmag	0.026	0.009	24
Fluctuation	3.611	0.082	24

Pearson Correlations

	Loudness	Loudness	SFM Pmag	Fluctuation
Loudness	1.000	-0.792	-0.488	-0.715
Loudness	-0.792	1.000	0.538	0.769
SFM Pmag	-0.488	0.538	1.000	0.479
Fluctuation	-0.715	0.769	0.479	1.000

Significance for Pearson Correlations

	Loudness	Loudness	SFM Pmag	Fluctuation
Loudness	-	0.000	0.016	0.000
Loudness	0.000	-	0.007	0.000
SFM Pmag	0.016	0.007	-	0.018
Fluctuation	0.000	0.000	0.018	-

Summary

R^2	R	Adj. R^2	S.E. of Estimate
0.657	0.811	0.606	0.300

ANOVA

Source	Sum Sq.	D.F.	Mean Sq.	F	Prob.
Regression	3.451	3	1.150	12.796	0.000
Residual	1.798	20	0.090		
Total	5.249	23			

Regression Coefficients

Source	Coefficient	Std Error	Std Beta	-95% C.I.	+95% C.I.	t	Prob.
Intercept	7.645	3.763		-0.205	15.494	2.032	0.056
Loudness	-0.593	0.225	-0.565	-1.063	-0.123	-2.631	0.016
SFM Pmag	-3.280	7.997	-0.064	-19.962	13.401	-0.410	0.686
Fluctuation	-1.458	1.205	-0.250	-3.971	1.055	-1.211	0.240

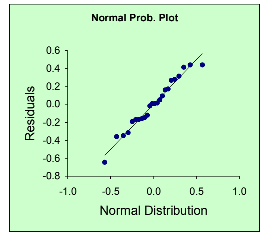
Residuals

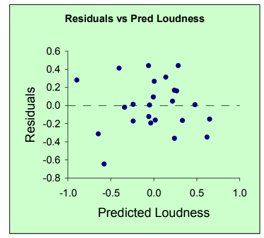
Pred Y	Std Pred Y	Residual	Pred Norm Res	Std Residual	Stu. Residual
0.241	0.630	-0.362	-0.429	-1.308	-1.333
-0.005	-0.006	0.094	0.105	0.335	0.327
-0.647	-1.663	-0.314	-0.295	-1.184	-1.197
0.267	0.695	0.160	0.137	0.568	0.558
-0.050	-0.122	0.005	-0.015	0.018	0.018
0.285	0.743	0.440	0.570	1.567	1.631
-0.059	-0.145	-0.122	-0.074	-0.417	-0.408
-0.897	-2.308	0.279	0.248	1.261	1.281
0.139	0.366	0.313	0.295	1.101	1.107
-0.404	-1.036	0.413	0.352	1.454	1.498
0.004	0.016	0.269	0.207	1.001	1.001
0.651	1.686	-0.149	-0.105	-0.555	-0.546
0.019	0.056	-0.161	-0.137	-0.559	-0.550
0.334	0.868	-0.166	-0.171	-0.596	-0.586
-0.339	-0.869	-0.019	-0.044	-0.068	-0.066
0.240	0.626	0.170	0.171	0.594	0.584
0.218	0.569	0.049	0.074	0.178	0.173
-0.062	-0.154	0.439	0.429	1.714	1.809
-0.240	-0.614	-0.172	-0.207	-0.603	-0.593
0.620	1.608	-0.350	-0.352	-1.375	-1.408
-0.242	-0.619	0.014	0.044	0.055	0.053
0.481	1.249	0.009	0.015	0.033	0.032
-0.036	-0.086	-0.193	-0.248	-0.671	-0.662
-0.580	-1.490	-0.647	-0.570	-2.436	-2.831

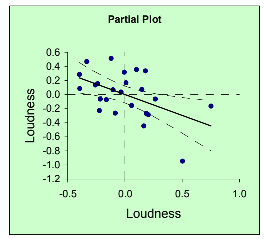
1 Case Critical Value for Studentised Residual (alpha = 0.05) 2.093
All Cases Critical Value for Studentised Residual (alpha = 0.05) 3.561

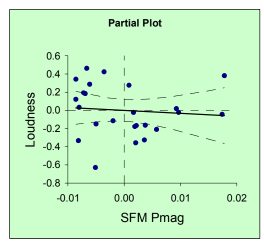
Partials

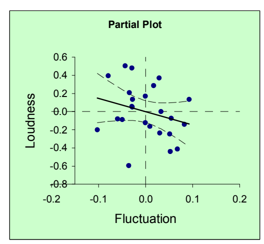
Y adj to Loudness	Y adj to SFM Pmag	Y adj to Fluctuation	Adj Loudness	Adj SFM Pmag	Adj Fluctuation
-0.230	-0.335	-0.438	-0.222	-0.008	0.052
-0.064	0.123	0.135	0.267	-0.009	-0.028
-0.265	-0.326	-0.413	-0.084	0.004	0.068
0.072	0.183	0.210	0.149	-0.007	-0.034
0.067	0.031	-0.074	-0.104	-0.008	0.055
0.334	0.462	0.503	0.179	-0.007	-0.043
-0.157	-0.116	-0.121	0.059	-0.002	-0.001
-0.167	0.277	0.395	0.752	0.001	-0.079
0.316	0.341	0.288	-0.005	-0.009	0.017
0.353	0.424	0.370	0.100	-0.004	0.029
0.467	0.289	0.134	-0.334	-0.006	0.092
0.085	-0.162	-0.163	-0.395	0.004	0.009
-0.271	-0.168	-0.088	0.186	0.002	-0.050
-0.287	-0.149	-0.079	0.204	-0.005	-0.059
0.135	-0.024	-0.139	-0.258	0.002	0.083
0.164	0.193	0.171	0.010	-0.007	-0.001
0.285	0.018	0.001	-0.398	0.009	0.033
0.511	0.380	0.481	-0.121	0.018	-0.029
-0.075	-0.178	-0.247	-0.163	0.002	0.052
-0.447	-0.357	-0.200	0.165	0.002	-0.103
0.035	-0.043	0.057	-0.035	0.017	-0.029
0.151	-0.023	0.050	-0.240	0.010	-0.028
-0.064	-0.211	-0.236	-0.216	0.006	0.030
-0.945	-0.630	-0.595	0.503	-0.005	-0.036











Appendix VI: Paired comparison study sound jury metrics t-test results.

Appendix VI-1: Subjective *Quality* t-test correlation coefficients (all) and significant correlations only (bottom).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.0235	0.6292	0.0058	0.1132	0.0091	0.0529	0.0016	0.2917	0.3501	0.4997	0.0691	0.4386	0.0018	0.0887	0.154	0.0579	0.0346	0.0656	0.1325	0.0106	0.219	0.0079	0.1983	0.1174	0.0043	0.0331	0.0008	0.0033	0.0075
2		1	0.0073	0.8819	0.3954	0.7622	0.4597	0.3269	0.2542	0.1077	0.095	0.3209	0.0898	0.7716	0.5213	0.3015	0.4262	0.8819	0.5244	0.3045	0.9681	0.2463	0.8116	0.0012	0.4379	0.9026	0.5512	0.6192	0.9566	0.8534
3			1	0.0013	0.0403	0.0025	0.0151	0.0004	0.1356	0.1488	0.2486	0.0195	0.2021	0.0004	0.0316	0.0572	0.0167	0.0113	0.0211	0.0465	0.0026	0.0893	0.0017	0.4016	0.0437	0.0009	0.0087	0.0001	0.0007	0.0016
4				1	0.8604	0.2423	0.4593	0.9916	0.1656	0.2184	0.0435	0.2046	9E-05	0.6269	0.5407	0.616	0.2807	0.6448	0.8914	0.3291	0.6922	0.1419	0.6031	0.0008	0.4298	0.7347	0.652	0.663	0.5	0.9475
5					1	0.2328	0.8293	0.0625	0.6901	0.4294	0.3585	0.9895	0.3634	0.1465	0.8483	0.8492	0.8731	0.491	0.8035	0.8753	0.3398	0.7249	0.3777	0.0068	0.9637	0.2867	0.6917	0.0854	0.2231	0.3546
6						1	0.263	0.4796	0.1469	0.0471	0.044	0.1613	0.0391	0.9264	0.3336	0.1663	0.2381	0.6504	0.3258	0.1647	0.6951	0.1333	0.5193	0.0004	0.2699	0.5879	0.3265	0.9114	0.7302	0.5594
7							1	0.0641	0.5346	0.2597	0.222	0.7744	0.214	0.1407	0.994	0.6657	0.9468	0.5741	0.9532	0.6846	0.3916	0.5477	0.4352	0.0023	0.8779	0.3099	0.8372	0.0681	0.2322	0.4055
8								1	0.0406	0.0087	0.009	0.0325	0.0073	0.3352	0.1035	0.0406	0.056	0.2621	0.0936	0.0386	0.2461	0.0323	0.1397	6E-05	0.0791	0.158	0.0824	0.4229	0.2264	0.1577
9									1	0.7798	0.6616	0.6578	0.689	0.0932	0.5777	0.8152	0.5653	0.3199	0.5317	0.7834	0.2098	0.9382	0.2274	0.0301	0.6703	0.1736	0.4336	0.058	0.1374	0.2142
10										1	0.8345	0.3432	0.8785	0.0107	0.3403	0.5483	0.2821	0.1502	0.284	0.5056	0.0606	0.6877	0.0491	0.0283	0.4237	0.0262	0.1781	0.004	0.0195	0.046
11											1	0.2886	0.9488	0.0147	0.2864	0.4555	0.2399	0.1302	0.2404	0.4192	0.0586	0.5739	0.0531	0.0574	0.3549	0.0328	0.1576	0.007	0.0248	0.0497
12												1	0.2818	0.0472	0.8135	0.8308	0.8278	0.4203	0.7549	0.8601	0.2314	0.6879	0.2209	0.0029	0.9477	0.1224	0.6011	0.0152	0.0891	0.2051
13													1	0.0095	0.2877	0.4675	0.2325	0.1256	0.2371	0.4276	0.0501	0.5956	0.0411	0.042	0.3607	0.0227	0.146	0.0038	0.017	0.0385
14														1	0.2568	0.0875	0.1167	0.6329	0.2314	0.0792	0.6649	0.0683	0.3652	7E-05	0.1922	0.4264	0.1906	0.7196	0.6739	0.4289
15															1	0.7074	0.9506	0.6265	0.9657	0.727	0.4827	0.5995	0.553	0.0054	0.8888	0.4533	0.874	0.1694	0.3649	0.5231
16																1	0.7061	0.3842	0.6555	0.9679	0.2406	0.8651	0.256	0.0099	0.8198	0.182	0.5343	0.0467	0.1392	0.2396
17																	1	0.5371	0.9059	0.7273	0.3531	0.5825	0.3847	0.0025	0.9201	0.2647	0.782	0.0536	0.1969	0.358
18																		1	0.6363	0.3904	0.896	0.317	0.9635	0.0018	0.5347	0.9385	0.6779	0.4915	0.805	0.9958
19																			1	0.6733	0.4784	0.547	0.5489	0.0033	0.8483	0.4364	0.904	0.1412	0.3434	0.5167
20																				1	0.2383	0.8303	0.2501	0.0077	0.8438	0.1718	0.5457	0.0395	0.1299	0.2335
21																					1	0.1907	0.8014	0.0004	0.3915	0.9192	0.4916	0.4725	0.8962	0.8563
22																						1	0.1995	0.0168	0.7025	0.1409	0.432	0.037	0.1081	0.1868
23																							1	0.0003	0.4421	0.8102	0.5649	0.1729	0.5993	0.9311
24																								1	0.0077	0.0002	0.0013	3E-05	0.0001	0.0003
25																									1	0.3516	0.7468	0.1219	0.2797	0.417
26																										1	0.4168	0.1809	0.7217	0.8952
27																											1	0.0935	0.3123	0.5264
28																												1	0.3957	0.2239
29																													1	0.6765
30																														1

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1		0.0235		0.0058		0.0091		0.0016						0.0018				0.0346			0.0106		0.0079			0.0043	0.0331	0.0008	0.0033	0.0075
2			0.0073																					0.0012						
3				0.0013	0.0403	0.0025	0.0151	0.0004				0.0195		0.0004	0.0316		0.0167	0.0113	0.0211	0.0465	0.0026		0.0017		0.0437	0.0009	0.0087	0.0001	0.0007	0.0016
4											0.0435		9E-05											0.0008						
5																								0.0068						
6										0.0471	0.044		0.0391											0.0004						
7																								0.0023						
8									0.0406	0.0087	0.009	0.0325	0.0073			0.0406				0.0386		0.0323		6E-05						
9																								0.0301						
10														0.0107									0.0491	0.0283		0.0262		0.004	0.0195	0.046
11														0.0147												0.0328		0.007	0.0248	0.0497
12														0.0472										0.0029				0.0152		
13														0.0095									0.0411	0.042		0.0227		0.0038	0.017	0.0385
14																								7E-05						
15																								0.0054						
16																								0.0099				0.0467		
17																								0.0025						
18																								0.0018						
19																								0.0033						
20																								0.0077				0.0395		
21																								0.0004						
22																								0.0168				0.037		
23																								0.0003						
24																									0.0077	0.0002	0.0013	3E-05	0.0001	0.0003
25																														
26																														
27																														
28																														
29																														
30																														

Appendix VI-2: Subjective *Naturalness* t-test correlation coefficients (all) and significant correlations only (bottom).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.0425	0.0464	0.0958	0.1608	0.0147	0.2657	0.1646	0.8741	0.5495	0.8995	0.4208	0.084	0.0295	0.3109	0.2482	0.4134	0.3618	0.1009	0.4244	0.2058	0.8396	0.1337	0.0839	0.4413	0.1038	0.1652	0.0346	0.0206	0.0621
2		1	0.0001	0.4546	0.4032	0.7696	0.1877	0.5225	0.0734	0.0923	0.0211	0.0863	0.0002	0.6285	0.2389	0.2706	0.1161	0.3224	0.5634	0.1381	0.3055	0.062	0.2319	0.0005	0.1925	0.2843	0.2665	0.6197	0.7173	0.4413
3			1	0.0002	0.0006	2E-05	0.0009	0.0012	0.0401	0.0057	0.0415	0.0017	0.5943	1E-05	0.0023	0.0013	0.0023	0.0072	0.0003	0.0033	0.0008	0.027	0.0001	0.8814	0.0065	9E-05	0.0003	2E-05	9E-06	5E-05
4				1	0.8604	0.2423	0.4593	0.9916	0.1656	0.2184	0.0435	0.2046	9E-05	0.6269	0.5407	0.616	0.2807	0.6448	0.8914	0.3291	0.6922	0.1419	0.6031	0.0008	0.4298	0.7347	0.652	0.663	0.5	0.9475
5					1	0.2212	0.6336	0.895	0.2457	0.3443	0.0926	0.3597	0.0007	0.5397	0.687	0.7695	0.4325	0.763	0.7778	0.4734	0.8471	0.2256	0.8156	0.0022	0.559	0.936	0.8333	0.5692	0.4401	0.799
6						1	0.0733	0.3325	0.0304	0.0319	0.0053	0.0244	1E-05	0.3464	0.1147	0.1304	0.0399	0.1899	0.3459	0.0538	0.1504	0.0227	0.0834	1E-04	0.0927	0.1107	0.1129	0.3459	0.4166	0.2118
7							1	0.5786	0.3891	0.5697	0.1589	0.6269	0.0008	0.1649	0.9871	0.8758	0.7161	0.9567	0.4337	0.7556	0.7807	0.3687	0.7004	0.0035	0.8323	0.5678	0.7414	0.1932	0.1107	0.3467
8								1	0.2394	0.3334	0.1048	0.3531	0.0017	0.7223	0.6251	0.6947	0.4107	0.6965	0.9043	0.4434	0.7603	0.2242	0.7245	0.0034	0.5154	0.8216	0.7433	0.7446	0.6282	0.9533
9									1	0.6965	0.7716	0.5759	0.0721	0.0672	0.4263	0.3563	0.5574	0.4647	0.1643	0.5615	0.306	0.9744	0.234	0.0713	0.5647	0.1905	0.2661	0.0753	0.0503	0.1229
10										1	0.4183	0.8644	0.0081	0.0636	0.6122	0.5121	0.821	0.644	0.2212	0.8144	0.4369	0.7012	0.3184	0.0158	0.7953	0.2466	0.3754	0.0765	0.042	0.1436
11											1	0.2782	0.0743	0.0073	0.2122	0.157	0.284	0.2762	0.0527	0.3031	0.1226	0.727	0.055	0.0815	0.3354	0.0389	0.083	0.0096	0.0044	0.0205
12												1	0.0014	0.0323	0.6767	0.5581	0.9349	0.7067	0.219	0.9195	0.4676	0.5668	0.2933	0.0066	0.8849	0.2077	0.3833	0.0455	0.0169	0.1047
13													1	2E-06	0.0032	0.0015	0.0026	0.0123	0.0003	0.0044	0.0009	0.0477	4E-05	0.7439	0.0105	2E-05	0.0002	4E-06	9E-07	1E-05
14														1	0.2762	0.3194	0.0779	0.4185	0.804	0.1191	0.373	0.0474	0.1637	0.0001	0.2176	0.251	0.2757	0.9675	0.8038	0.588
15															1	0.9033	0.7455	0.9699	0.5005	0.7758	0.8208	0.4137	0.7754	0.0069	0.839	0.6653	0.7965	0.3007	0.2132	0.4601
16																1	0.6345	0.9493	0.5655	0.6714	0.9149	0.3388	0.8875	0.0042	0.7467	0.766	0.8997	0.3474	0.2455	0.5317
17																	1	0.759	0.2799	0.9805	0.5473	0.5493	0.4185	0.0079	0.9387	0.323	0.4832	0.0955	0.0494	0.1847
18																		1	0.5945	0.7817	0.8805	0.4595	0.8592	0.0152	0.8326	0.7704	0.868	0.4379	0.354	0.5904
19																			1	0.3186	0.6307	0.1451	0.5567	0.0012	0.4029	0.6611	0.5951	0.8296	0.6892	0.9216
20																				1	0.5883	0.5557	0.4868	0.0099	0.9577	0.392	0.5364	0.1379	0.0829	0.2417
21																					1	0.286	0.994	0.003	0.6718	0.8662	0.9952	0.4036	0.2887	0.6098
22																						1	0.2012	0.0534	0.5623	0.1585	0.2393	0.0549	0.0335	0.0965
23																							1	0.0009	0.6097	0.794	0.9992	0.2122	0.0893	0.4404
24																								1	0.0155	0.0006	0.0015	0.0002	9E-05	0.0003
25																									1	0.5201	0.6385	0.2365	0.1697	0.3595
26																										1	0.8404	0.3076	0.1478	0.5928
27																											1	0.3147	0.1903	0.5385
28																												1	0.7859	0.64
29																													1	0.4268
30																														1

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1		0.0425	0.0464			0.0147								0.0295														0.0346	0.0206	
2			0.0001								0.0211		0.0002											0.0005						
3				0.0002	0.0006	2E-05	0.0009	0.0012	0.0401	0.0057	0.0415	0.0017		1E-05	0.0023	0.0013	0.0023	0.0072	0.0003	0.0033	0.0008	0.027	0.0001		0.0065	9E-05	0.0003	2E-05	9E-06	5E-05
4											0.0435		9E-05											0.0008						
5													0.0007											0.0022						
6									0.0304	0.0319	0.0053	0.0244	1E-05				0.0399					0.0227		1E-04						
7													0.0008											0.0035						
8													0.0017											0.0034						
9																														
10													0.0081											0.0158					0.042	
11														0.0073												0.0389		0.0096	0.0044	0.0205
12													0.0014	0.0323										0.0066				0.0455	0.0169	
13														2E-06	0.0032	0.0015	0.0026	0.0123	0.0003	0.0044	0.0009	0.0477	4E-05		0.0105	2E-05	0.0002	4E-06	9E-07	1E-05
14																						0.0474		0.0001						
15																								0.0069						
16																								0.0042						
17																								0.0079					0.0494	
18																								0.0152						
19																								0.0012						
20																								0.0099						
21																								0.003						
22																													0.0335	
23																								0.0009						
24																									0.0155	0.0006	0.0015	0.0002	9E-05	0.0003
25																														
26																														
27																														
28																														
29																														
30																														

Appendix VI-3: Subjective *Pitch* t-test correlation coefficients (all) and significant correlations only (bottom).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.0412	0.0008	0.0171	0.5173	0.0127	0.0361	1E-07	0.0049	0.0336	0.6597	0.3412	0.321	0.7854	0.1446	0.0863	0.0255	0.0003	0.0015	0.2892	0.1596	0.1581	0.0889	0.0161	0.1225	0.0671	0.0492	0.166	0.1212	0.1307
2		1	2E-06	0.9396	0.0071	0.6167	6E-05	3E-11	0.3959	9E-05	0.0907	0.1835	0.0035	0.0372	0.0012	0.5656	3E-05	3E-07	9E-07	0.0017	0.0006	0.0019	7E-05	0.5519	0.0012	5E-05	3E-05	0.0002	0.0001	0.0001
3			1	4E-07	0.0034	5E-07	0.061	0.2121	2E-07	0.1129	0.0002	3E-05	0.0104	0.0001	0.042	3E-06	0.0713	0.9164	0.3882	0.0065	0.0155	0.0534	0.0072	1E-06	0.066	0.0116	0.0141	0.0044	0.0072	0.0047
4				1	0.0015	0.4975	2E-06	6E-14	0.2731	1E-05	0.045	0.1053	0.0007	0.0079	0.0003	0.5137	6E-07	2E-08	1E-08	0.0001	4E-05	0.0006	3E-08	0.4499	0.0003	4E-08	1E-08	5E-07	4E-07	9E-08
5					1	0.0018	0.1363	1E-06	0.0006	0.1159	0.2629	0.0923	0.7004	0.3018	0.3671	0.0143	0.1038	0.0017	0.0083	0.6908	0.4425	0.3775	0.3433	0.0029	0.3098	0.2687	0.213	0.5303	0.4139	0.4589
6						1	1E-05	5E-12	0.7285	2E-05	0.03	0.0645	0.0009	0.0096	0.0003	0.2635	5E-06	6E-08	2E-07	0.0004	0.0001	0.0005	1E-05	0.8897	0.0003	8E-06	5E-06	4E-05	2E-05	2E-05
7							1	0.0001	3E-06	0.8185	0.0089	0.0011	0.3039	0.0065	0.682	7E-05	0.904	0.0485	0.2003	0.2464	0.4506	0.7223	0.3438	4E-05	0.8196	0.4733	0.5533	0.2203	0.3234	0.2409
8								1	1E-12	0.001	8E-09	2E-10	1E-05	9E-10	0.0002	5E-12	0.0002	0.1291	0.0095	2E-06	1E-05	0.0005	3E-07	1E-10	0.0007	9E-07	1E-06	1E-07	4E-07	1E-07
9									1	6E-06	0.0121	0.0268	0.0003	0.0031	0.0001	0.1342	1E-06	2E-08	4E-08	0.0001	3E-05	0.0002	3E-06	0.8587	0.0001	2E-06	1E-06	9E-06	6E-06	5E-06
10										1	0.0097	0.0017	0.2486	0.0082	0.5612	0.0001	0.901	0.1027	0.3468	0.2032	0.3635	0.6005	0.2795	5E-05	0.6846	0.3763	0.4361	0.1863	0.2637	0.2029
11											1	0.6123	0.1474	0.818	0.0585	0.1894	0.0057	6E-05	0.0002	0.1171	0.0558	0.0692	0.019	0.0355	0.0506	0.014	0.0092	0.0451	0.0308	0.0312
12												1	0.0465	0.4046	0.0163	0.3802	0.0006	5E-06	2E-05	0.0285	0.0112	0.0222	0.0013	0.072	0.015	0.001	0.0005	0.0047	0.003	0.0025
13													1	0.1628	0.6016	0.0068	0.2493	0.0067	0.0309	0.9815	0.7369	0.5999	0.6848	0.0015	0.515	0.5678	0.4863	0.9046	0.7581	0.8339
14														1	0.0612	0.0792	0.0037	3E-05	0.0001	0.1223	0.0533	0.0747	0.0097	0.0145	0.0534	0.0072	0.004	0.0323	0.0208	0.0186
15															1	0.0023	0.6044	0.0345	0.1324	0.5594	0.8093	0.9778	0.778	0.0005	0.8843	0.9094	0.9954	0.5968	0.7289	0.6435
16																1	3E-05	4E-07	7E-07	0.0029	0.001	0.0038	4E-05	0.251	0.0024	3E-05	1E-05	0.0002	0.0001	8E-05
17																	1	0.0577	0.2355	0.1935	0.3751	0.648	0.261	2E-05	0.7424	0.3776	0.4485	0.1607	0.2482	0.175
18																		1	0.4021	0.0034	0.0097	0.0464	0.0031	2E-07	0.0585	0.0056	0.0071	0.0017	0.0032	0.0018
19																			1	0.017	0.0464	0.1637	0.0151	9E-07	0.201	0.0289	0.0367	0.0082	0.0161	0.0085
20																				1	0.6921	0.5615	0.6141	0.0008	0.4736	0.4907	0.403	0.8655	0.7013	0.7821
21																					1	0.7962	0.9989	0.0003	0.6961	0.8412	0.7355	0.7563	0.9284	0.8231
22																						1	0.7675	0.0008	0.9105	0.8886	0.9679	0.5999	0.7219	0.6437
23																							1	6E-05	0.6537	0.767	0.6102	0.6412	0.8947	0.724
24																								1	0.0005	5E-05	3E-05	0.0002	0.0001	0.0001
25																									1	0.7728	0.8501	0.4986	0.6138	0.537
26																										1	0.8495	0.4767	0.6964	0.5329
27																											1	0.3569	0.5605	0.3957
28																												1	0.7694	0.8861
29																													1	0.8591
30																														1

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1		0.0412	0.0008	0.0171		0.0127	0.0361	1E-07	0.0049	0.0336							0.0255	0.0003	0.0015					0.0161			0.0492			
2			2E-06		0.0071		6E-05	3E-11		9E-05			0.0035	0.0372	0.0012		3E-05	3E-07	9E-07	0.0017	0.0006	0.0019	7E-05		0.0012	5E-05	3E-05	0.0002	0.0001	0.0001
3				4E-07	0.0034	5E-07			2E-07		0.0002	3E-05	0.0104	0.0001	0.042	3E-06				0.0065	0.0155		0.0072	1E-06		0.0116	0.0141	0.0044	0.0072	0.0047
4					0.0015		2E-06	6E-14		1E-05	0.045		0.0007	0.0079	0.0003		6E-07	2E-08	1E-08	0.0001	4E-05	0.0006	3E-08		0.0003	4E-08	1E-08	5E-07	4E-07	9E-08
5						0.0018		1E-06	0.0006							0.0143		0.0017	0.0083					0.0029						
6							1E-05	5E-12		2E-05	0.03		0.0009	0.0096	0.0003		5E-06	6E-08	2E-07	0.0004	0.0001	0.0005	1E-05		0.0003	8E-06	5E-06	4E-05	2E-05	2E-05
7								0.0001	3E-06		0.0089	0.0011		0.0065		7E-05		0.0485						4E-05						
8									1E-12	0.001	8E-09	2E-10	1E-05	9E-10	0.0002	5E-12	0.0002		0.0095	2E-06	1E-05	0.0005	3E-07	1E-10	0.0007	9E-07	1E-06	1E-07	4E-07	1E-07
9										6E-06	0.0121	0.0268	0.0003	0.0031	0.0001		1E-06	2E-08	4E-08	0.0001	3E-05	0.0002	3E-06		0.0001	2E-06	1E-06	9E-06	6E-06	5E-06
10											0.0097	0.0017		0.0082		0.0001								5E-05						
11																	0.0057	6E-05	0.0002				0.019	0.0355		0.014	0.0092	0.0451	0.0308	0.0312
12													0.0465		0.0163		0.0006	5E-06	2E-05	0.0285	0.0112	0.0222	0.0013		0.015	0.001	0.0005	0.0047	0.003	0.0025
13																0.0068		0.0067	0.0309					0.0015						
14																	0.0037	3E-05	0.0001				0.0097	0.0145		0.0072	0.004	0.0323	0.0208	0.0186
15																0.0023		0.0345						0.0005						
16																	3E-05	4E-07	7E-07	0.0029	0.001	0.0038	4E-05		0.0024	3E-05	1E-05	0.0002	0.0001	8E-05
17																								2E-05						
18																				0.0034	0.0097	0.0464	0.0031	2E-07		0.0056	0.0071	0.0017	0.0032	0.0018
19																				0.017	0.0464		0.0151	9E-07		0.0289	0.0367	0.0082	0.0161	0.0085
20																								0.0008						
21																								0.0003						
22																								0.0008						
23																								6E-05						
24																									0.0005	5E-05	3E-05	0.0002	0.0001	0.0001
25																														
26																														
27																														
28																														
29																														
30																														

Appendix VI-4: Subjective *Duration* t-test correlation coefficients (all) and significant correlations only (bottom).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.3135	0.0351	0.317	0.0056	0.4276	0.0074	5E-07	0.9778	0.0306	0.7836	0.0654	0.9897	0.0056	0.0289	0.4621	0.0108	0.0002	0.0431	0.1065	0.0399	0.0937	0.004	0.0558	3E-05	0.0032	0.0005	0.0004	0.0007	0.0039
2		1	0.2133	0.9098	0.1042	0.0741	0.1286	5E-05	0.3575	0.2803	0.217	0.4971	0.2819	0.1409	0.2418	0.6906	0.1817	0.0056	0.3033	0.5628	0.3529	0.51	0.1226	0.0072	0.0017	0.1035	0.0293	0.0259	0.0389	0.1285
3			1	0.1548	0.984	0.006	0.9317	0.0163	0.046	0.7024	0.0231	0.4255	0.0274	0.7897	0.8154	0.0944	0.7677	0.23	0.7377	0.4425	0.5808	0.4956	0.8016	0.0006	0.14	0.8678	0.7869	0.7557	0.8568	0.7578
4				1	0.0506	0.0607	0.065	6E-06	0.3693	0.1869	0.2126	0.3678	0.2762	0.0615	0.1631	0.749	0.096	0.0018	0.2173	0.4512	0.2427	0.4028	0.0476	0.0053	0.0004	0.0386	0.0064	0.0054	0.0096	0.048
5					1	0.0003	0.8838	0.0022	0.011	0.5941	0.0034	0.2593	0.0024	0.6678	0.7456	0.02	0.6539	0.1284	0.6524	0.3065	0.4382	0.3669	0.6759	4E-05	0.0563	0.7753	0.7023	0.656	0.8081	0.6043
6						1	0.0003	1E-08	0.4438	0.0028	0.6322	0.006	0.3772	0.0002	0.0031	0.1024	0.0005	7E-06	0.0055	0.016	0.0034	0.0142	9E-05	0.1909	9E-07	7E-05	6E-06	5E-06	1E-05	8E-05
7							1	0.0013	0.0142	0.6862	0.0045	0.3179	0.0033	0.7904	0.84	0.0263	0.7647	0.0968	0.7398	0.3647	0.5193	0.4315	0.8053	5E-05	0.0395	0.9097	0.5652	0.5222	0.6663	0.7321
8								1	2E-06	0.0008	4E-07	7E-05	1E-07	0.0002	0.0025	1E-06	0.0004	0.152	0.0021	0.0003	0.0003	0.0005	0.0002	5E-09	0.2305	0.0003	0.0012	0.0014	0.0009	0.0001
9									1	0.0463	0.776	0.0944	0.9856	0.0129	0.0421	0.5168	0.0207	0.0004	0.0596	0.1369	0.06	0.1211	0.0101	0.0653	0.0001	0.0083	0.0017	0.0015	0.0024	0.0102
10										1	0.019	0.6078	0.0193	0.8255	0.871	0.0985	0.8793	0.0572	0.9746	0.624	0.838	0.6994	0.7961	0.0003	0.0229	0.7121	0.3255	0.2983	0.3922	0.8469
11											1	0.0405	0.7572	0.0035	0.0182	0.3176	0.0066	0.0001	0.0274	0.069	0.0246	0.0608	0.0025	0.1029	2E-05	0.002	0.0003	0.0003	0.0005	0.0025
12												1	0.0428	0.3689	0.5166	0.2082	0.4475	0.0133	0.6183	0.9703	0.7517	0.948	0.3284	0.0006	0.0037	0.2764	0.0723	0.0627	0.0992	0.3491
13													1	0.0017	0.0195	0.4229	0.0046	6E-05	0.031	0.0832	0.025	0.0729	0.001	0.0417	9E-06	0.0008	6E-05	5E-05	0.0001	0.0009
14														1	0.9933	0.0204	0.9454	0.0413	0.875	0.429	0.6252	0.5104	0.9661	3E-05	0.0121	0.8375	0.267	0.2322	0.3592	0.9466
15															1	0.0891	0.9678	0.0993	0.9042	0.537	0.7199	0.6046	0.9721	0.0003	0.0468	0.8903	0.491	0.4594	0.5655	0.9755
16																1	0.0391	0.0006	0.1262	0.2901	0.1296	0.2562	0.014	0.009	0.0001	0.0111	0.0013	0.001	0.0021	0.0133
17																	1	0.0491	0.9194	0.4902	0.6941	0.5694	0.9134	7E-05	0.0165	0.805	0.3121	0.2793	0.3953	0.9832
18																		1	0.0828	0.0229	0.0316	0.0313	0.038	1E-06	0.7713	0.0503	0.1423	0.156	0.1169	0.0287
19																			1	0.629	0.8266	0.6983	0.8511	0.0005	0.0386	0.7749	0.4118	0.3841	0.4776	0.8981
20																				1	0.7536	0.927	0.3981	0.0014	0.0083	0.3467	0.1297	0.1171	0.1626	0.4229
21																					1	0.8344	0.5879	0.0003	0.0108	0.5125	0.1881	0.1686	0.2387	0.6286
22																						1	0.4802	0.0013	0.0122	0.4229	0.1742	0.1586	0.2137	0.5099
23																							1	3E-05	0.0103	0.8576	0.2378	0.2024	0.3348	0.8994
24																								1	2E-07	2E-05	4E-06	3E-06	6E-06	3E-05
25																									1	0.0148	0.0526	0.0591	0.0413	0.0071
26																										1	0.3386	0.2948	0.4523	0.7514
27																											1	0.9239	0.8375	0.1528
28																												1	0.7646	0.125
29																													1	0.2354
30																														1

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1			0.0351		0.0056		0.0074	5E-07		0.0306				0.0056	0.0289		0.0108	0.0002	0.0431		0.0399		0.004		3E-05	0.0032	0.0005	0.0004	0.0007	0.0039
2								5E-05										0.0056						0.0072	0.0017		0.0293	0.0259	0.0389	
3						0.006		0.0163	0.046		0.0231		0.0274											0.0006						
4								6E-06										0.0018					0.0476	0.0053	0.0004	0.0386	0.0064	0.0054	0.0096	0.048
5						0.0003		0.0022	0.011		0.0034		0.0024			0.02								4E-05						
6							0.0003	1E-08		0.0028		0.006		0.0002	0.0031		0.0005	7E-06	0.0055	0.016	0.0034	0.0142	9E-05		9E-07	7E-05	6E-06	5E-06	1E-05	8E-05
7								0.0013	0.0142		0.0045		0.0033			0.0263								5E-05	0.0395					
8									2E-06	0.0008	4E-07	7E-05	1E-07	0.0002	0.0025	1E-06	0.0004		0.0021	0.0003	0.0003	0.0005	0.0002	5E-09		0.0003	0.0012	0.0014	0.0009	0.0001
9										0.0463				0.0129	0.0421		0.0207	0.0004					0.0101		0.0001	0.0083	0.0017	0.0015	0.0024	0.0102
10											0.019		0.0193											0.0003	0.0229					
11												0.0405		0.0035	0.0182		0.0066	0.0001	0.0274		0.0246		0.0025		2E-05	0.002	0.0003	0.0003	0.0005	0.0025
12													0.0428					0.0133						0.0006	0.0037					
13														0.0017	0.0195		0.0046	6E-05	0.031		0.025		0.001	0.0417	9E-06	0.0008	6E-05	5E-05	0.0001	0.0009
14																0.0204		0.0413						3E-05	0.0121					
15																								0.0003	0.0468					
16																	0.0391	0.0006					0.014	0.009	0.0001	0.0111	0.0013	0.001	0.0021	0.0133
17																		0.0491						7E-05	0.0165					
18																				0.0229	0.0316	0.0313	0.038	1E-06						0.0287
19																								0.0005	0.0386					
20																								0.0014	0.0083					
21																								0.0003	0.0108					
22																								0.0013	0.0122					
23																								3E-05	0.0103					
24																									2E-07	2E-05	4E-06	3E-06	6E-06	3E-05
25																										0.0148			0.0413	0.0071
26																														
27																														
28																														
29																														
30																														

Appendix VI-5: Subjective *Loudness* t-test correlation coefficients (all) and significant correlations only (bottom).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0.3617	0.0027	0.0101	0.701	0.0001	0.7465	0.0427	0.013	0.5708	0.0565	0.003	0.9231	0.1426	0.3022	0.0176	0.0667	0.063	0.1629	0.0521	0.6074	0.0089	0.5574	0.0002	0.0051	0.9148	0.931	0.9989	0.591	0.9654
2		1	0.0004	0.1355	0.5325	0.0057	0.1917	0.0072	0.1347	0.739	0.4073	0.0641	0.3238	0.7118	0.0709	0.1748	0.4318	0.3013	0.0283	0.4028	0.1641	0.102	0.1214	2E-05	0.0358	0.2521	0.317	0.3271	0.1199	0.2545
3			1	2E-06	0.0007	3E-08	0.0028	0.241	4E-06	0.001	2E-05	7E-07	0.0037	5E-05	0.0357	5E-06	2E-05	5E-05	0.0419	1E-05	0.0078	3E-06	0.0046	0.4067	5E-06	0.0015	0.0009	0.0017	0.0029	0.001
4				1	0.0157	0.1392	0.0013	4E-05	0.9076	0.0631	0.4336	0.7055	0.0089	0.1737	0.0008	0.9357	0.4306	0.8456	9E-05	0.4167	0.002	0.7761	0.0005	9E-08	0.2629	0.0017	0.0023	0.005	0.0003	0.0012
5					1	0.0001	0.42	0.0142	0.0206	0.8019	0.092	0.0043	0.6315	0.2329	0.148	0.0281	0.1083	0.0971	0.058	0.0851	0.345	0.014	0.2685	3E-05	0.0078	0.5539	0.6935	0.6713	0.2693	0.5755
6						1	4E-06	3E-07	0.2143	0.0018	0.0232	0.2516	0.0001	0.004	8E-06	0.1392	0.0254	0.1793	3E-07	0.0195	1E-05	0.2882	1E-06	1E-09	0.895	4E-06	5E-06	3E-05	4E-07	2E-06
7							1	0.0499	0.0025	0.3529	0.0118	0.0002	0.8366	0.0389	0.3901	0.0033	0.0162	0.0254	0.2033	0.0097	0.7955	0.0016	0.7551	0.0001	0.0018	0.7797	0.5913	0.7151	0.8167	0.6923
8								1	7E-05	0.0159	0.0003	1E-05	0.0552	0.0009	0.3119	9E-05	0.0004	0.0009	0.3866	0.0003	0.1067	4E-05	0.0767	0.0429	7E-05	0.0282	0.0169	0.0309	0.0542	0.0198
9									1	0.0664	0.4049	0.8208	0.0114	0.1755	0.0012	0.853	0.4018	0.7811	0.0002	0.3904	0.0031	0.8747	0.0011	2E-07	0.3194	0.0034	0.0046	0.0077	0.0008	0.0027
10										1	0.2289	0.0262	0.517	0.4498	0.1343	0.0878	0.2493	0.1838	0.0619	0.2229	0.2934	0.0487	0.2402	5E-05	0.0188	0.4516	0.552	0.542	0.2456	0.4666
11											1	0.2347	0.0492	0.5718	0.0056	0.5108	0.9779	0.6832	0.0009	0.9921	0.0145	0.3194	0.005	6E-07	0.1019	0.0164	0.0224	0.0363	0.0034	0.0129
12												1	0.0027	0.0725	0.0002	0.6605	0.2375	0.625	2E-05	0.2189	0.0005	0.9594	7E-05	3E-08	0.3754	0.0003	0.0004	0.0012	3E-05	0.0002
13													1	0.1243	0.3542	0.0154	0.0582	0.0557	0.2034	0.0454	0.6844	0.0078	0.6442	0.0002	0.0045	0.9925	0.8404	0.9153	0.6861	0.9375
14														1	0.016	0.232	0.6039	0.4043	0.0031	0.5676	0.0422	0.1298	0.0174	2E-06	0.0453	0.0547	0.0746	0.1039	0.0128	0.046
15															1	0.0016	0.0071	0.0098	0.8089	0.0049	0.5681	0.0008	0.5247	0.0034	0.0007	0.2746	0.196	0.2666	0.4503	0.2274
16																1	0.5048	0.9012	0.0003	0.4957	0.0042	0.7297	0.0014	2E-07	0.2513	0.0045	0.006	0.0104	0.001	0.0035
17																	1	0.6728	0.0013	0.985	0.0184	0.3185	0.0073	9E-07	0.1022	0.0225	0.0306	0.0453	0.0055	0.0187
18																		1	0.0034	0.6735	0.0235	0.6797	0.015	3E-06	0.2568	0.0339	0.0436	0.0505	0.0142	0.0327
19																			1	0.0007	0.3704	0.0001	0.3042	0.0037	0.0003	0.119	0.0707	0.1262	0.2298	0.0836
20																				1	0.0127	0.3057	0.0039	5E-07	0.0972	0.0135	0.0184	0.0321	0.0025	0.0101
21																					1	0.0021	0.9992	0.0005	0.0017	0.6142	0.4709	0.5732	0.9258	0.5427
22																						1	0.0007	1E-07	0.3828	0.0022	0.003	0.0051	0.0005	0.0017
23																							1	0.0002	0.0011	0.5369	0.3691	0.507	0.906	0.44
24																								1	3E-07	7E-05	4E-05	9E-05	0.0001	5E-05
25																									1	0.0024	0.0031	0.0038	0.001	0.0023
26																										1	0.7926	0.9017	0.5662	0.9233
27																											1	0.9223	0.3692	0.8458
28																												1	0.5345	0.9584
29																													1	0.4475
30																														1

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1			0.0027	0.0101		0.0001		0.0427	0.013			0.003				0.0176						0.0089		0.0002	0.0051					
2			0.0004			0.0057		0.0072											0.0283					2E-05	0.0358					
3				2E-06	0.0007	3E-08	0.0028		4E-06	0.001	2E-05	7E-07	0.0037	5E-05	0.0357	5E-06	2E-05	5E-05	0.0419	1E-05	0.0078	3E-06	0.0046		5E-06	0.0015	0.0009	0.0017	0.0029	0.001
4					0.0157		0.0013	4E-05					0.0089		0.0008				9E-05		0.002		0.0005	9E-08		0.0017	0.0023	0.005	0.0003	0.0012
5						0.0001		0.0142	0.0206			0.0043				0.0281						0.014		3E-05	0.0078					
6							4E-06	3E-07		0.0018	0.0232		0.0001	0.004	8E-06		0.0254		3E-07	0.0195	1E-05		1E-06	1E-09		4E-06	5E-06	3E-05	4E-07	2E-06
7								0.0499	0.0025		0.0118	0.0002		0.0389		0.0033	0.0162	0.0254		0.0097		0.0016		0.0001	0.0018					
8									7E-05	0.0159	0.0003	1E-05		0.0009		9E-05	0.0004	0.0009		0.0003		4E-05		0.0429	7E-05	0.0282	0.0169	0.0309		0.0198
9													0.0114		0.0012				0.0002		0.0031		0.0011	2E-07		0.0034	0.0046	0.0077	0.0008	0.0027
10												0.0262										0.0487		5E-05	0.0188					
11													0.0492		0.0056				0.0009		0.0145		0.005	6E-07		0.0164	0.0224	0.0363	0.0034	0.0129
12													0.0027		0.0002				2E-05		0.0005		7E-05	3E-08		0.0003	0.0004	0.0012	3E-05	0.0002
13																0.0154				0.0454		0.0078		0.0002	0.0045					
14															0.016				0.0031		0.0422		0.0174	2E-06	0.0453				0.0128	0.046
15																0.0016	0.0071	0.0098		0.0049		0.0008		0.0034	0.0007					
16																			0.0003		0.0042		0.0014	2E-07		0.0045	0.006	0.0104	0.001	0.0035
17																			0.0013		0.0184		0.0073	9E-07		0.0225	0.0306	0.0453	0.0055	0.0187
18																			0.0034		0.0235		0.015	3E-06		0.0339	0.0436		0.0142	0.0327
19																				0.0007		0.0001		0.0037	0.0003					
20																					0.0127		0.0039	5E-07		0.0135	0.0184	0.0321	0.0025	0.0101
21																						0.0021		0.0005	0.0017					
22																							0.0007	1E-07		0.0022	0.003	0.0051	0.0005	0.0017
23																								0.0002	0.0011					
24																									3E-07	7E-05	4E-05	9E-05	0.0001	5E-05
25																										0.0024	0.0031	0.0038	0.001	0.0023
26																														
27																														
28																														
29																														
30																														

SOUND QUALITY OF LAMINATE FLOORING

SOUND JURY EVALUATION

SUBJECT QUESTIONAIRE PACKET

Georgia Institute of Technology
Project Title: Sound Quality of Laminate Flooring
Investigators: *Dr Ken Cunefare, James Wilson*
Research Consent Form

You are being asked to be a volunteer in a research study.

Purpose:
The purpose of this study is:
The purpose of this study is to determine specific acoustic metrics that describe the sound quality of laminate flooring systems. The quantifiable metrics will be correlated to sound jury perceptions. A total of twenty subjects will be used for the study.

Procedures:
If you decide to be in this study, your part will involve:

You will first submit to a hearing test for screening purposes. This is an automated test, similar to those employed in public schools. After the screening, you will participate in a series of listening experiments, where you will rate recorded sounds based on your perception of the sound. There will be three experiments in total. The whole sequence of experiments will require approximately 2 hours to complete.

Risks/Discomforts
The following risks/discomforts may occur as a result of your participation in this study:
The risks involved are no greater than those involved in daily activities such as listening to music at a comfortable volume over a pair of headphones.

Benefits
The following benefits to you are possible as a result of being in this study:
You are not likely to benefit in any way from joining this study. But we hope that future flooring products will benefit from what we find in doing this study.

Compensation to You
You will be offered a US$10 gift card for Barnes and Nobles bookstore for completing the study. If a subject does not quality for the experiment, due to the screening process or that they leave in the middle of the study, they will receive a US$5 gift card for Barnes and Nobles bookstore.

Confidentiality
The following procedures will be followed to keep your personal information confidential in this study: The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published.
To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB will review study records. Members of the Food and Drug Administration may also look over study records during required reviews. The Office of Human Research Protections may also look at study records.

Costs to You
There are no costs to you for participating in this study, except for your time.

Subject Rights
Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
Any new information that may make you change your mind about being in this study will be given to you.
You will be given a copy of this consent form to keep.
You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject
If you have any questions about the study, you may contact Dr. K. Cunefare, at telephone (404) 894-4726).
If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark, Georgia Institute of Technology at (404) 894-6942.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

____
Subject Name

____
Subject Signature **Date**

____
Signature of Person Obtaining Consent **Date**

Georgia Institute of Technology
Project Title: Sound Quality of Laminate Flooring Systems
Investigators: James Wilson, Professor Ken Cunefare

<u>Questionnaire</u>

Research Subject Number: ____________

Male or Female? (circle one)

Are you aware of an existing hearing impairment?

YES NO (circle one)

Have you had a cold or other sinus infection/illness in the past month?

YES NO (circle one)

Do you currently live in a space with either laminate or natural wood floors?

YES NO (circle one)

Training Sounds

To complete the sound jury survey, some training is required, so that you, the subject, understand what the questionnaire is asking for. Please read the definitions below and listen to all accompanying training sounds. When completing the study, please follow the guidelines for each category as faithfully as possible.

When responding to the questionnaire, you are asked to rate each sample in five categories.

1. Naturalness
   For the naturalness category, you are asked to rate the floor for how natural you feel the sound is. Please use your previous experience with hardwood floors as the reference for this category.

2. Quality Floor
   For the quality floor category, you are asked to rate how strongly you feel the quality of the floor is based on how you perceive its sound. Please use your previous experience with hardwood floors as the reference for this category.

3. Pitch
   For the pitch category, you are asked to rate how low or how high the perceived pitch of the floor sample is. In layman's terms, pitch is how you perceive a musical note. Please take this time now to play the training sounds for pitch. You will first hear the low pitch impact three times, followed by the high impact three times. Listen as many times as you feel necessary.

4. Duration
   For the duration category, you are asked to rate how sharp or hollow the perceived duration of the floor sample is. Sharper sounds have little to no perceivable echo, while hollow sounds have a fairly high amount of perceived echo. Please take this time now to play the training sounds for duration. You will first hear the sharp impact three times, followed by the hollow impact three times. Listen as many times as you feel necessary.

5. Loudness
   For the loudness category, you are asked to rate how loud or soft the perceived loudness of the floor sample is. Please take this time now to play the training sounds for loudness. You will first hear the loud impact three times, followed by the soft impact three times. Listen as many times as you feel necessary.

Now that you have read the definitions for each category, please continue to the next page to read the instructions for the study.

Instructions (24 Samples):

For this portion of the sound jury evaluation, you are asked to listen to an impact sound created on a flooring product. You will then be asked to evaluate that sound on several descriptive response scales. Each category is listed, followed by an adjective pair. Each adjective pair consists of a descriptive adjective and its antonym. In between each adjective pair, there is a graduated scale that represents different magnitudes between each adjective pair. Please choose the point on the scale, which best represents your impression of the sound for each descriptor.

As an example, a study created to determine the perceived strength for a cup of coffee might consist of a descriptive response scale similar to the one below:

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Flavor Strength	Mild								Bold

You, the subject, will test the cup of coffee and then rate your impression of the strength, based on the graduated scale (extremely, very, somewhat, neither, ……). If you feel that the cup of coffee was served to you far too mild cold or far too bold, then the most appropriate response might be “Extremely” Mild or “Extremely” Bold. If the cup was served near your preferred strength, then you might respond with “Neither”. If the cup of coffee is a little too mild or a little too bold, then the descriptors “Very” or “Somewhat” may be the appropriate response for you to give in the survey.

Please circle the vertical tick mark to indicate your answer.

When you are ready to begin the evaluation, please press “OK” on the “Testing about to begin.” dialogue box.

Sample 1

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 2

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 3

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 4

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 5

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 6

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 7

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 8

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 9

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 10

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 11

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 12

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 13

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 14

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 15

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial								Natural
Quality Floor	Low Quality								High Quality
Pitch	Bright								Dull
Duration	Hollow								Sharp
Loudness	Loud								Soft

Sample 16

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 17

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 18

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 19

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 20

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 21

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 22

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 23

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

Sample 24

		Extremely	Very	Somewhat	Neither	Somewhat	Very	Extremely	
Naturalness	Artificial	|	|	|	|	|	|	|	Natural
Quality Floor	Low Quality	|	|	|	|	|	|	|	High Quality
Pitch	Bright	|	|	|	|	|	|	|	Dull
Duration	Hollow	|	|	|	|	|	|	|	Sharp
Loudness	Loud	|	|	|	|	|	|	|	Soft

THANK YOU FOR PARTICIPATING IN THE STUDY!

SOUND QUALITY OF LAMINATE FLOORING

SOUND JURY EVALUATION

SUBJECT QUESTIONAIRE PACKET

Georgia Institute of Technology
Project Title: Sound Quality of Laminate Flooring
Investigators: *Dr Ken Cunefare, James Wilson*
Research Consent Form

You are being asked to be a volunteer in a research study.

Purpose:
The purpose of this study is:
The purpose of this study is to determine specific acoustic metrics that describe the sound quality of laminate flooring systems. The quantifiable metrics will be correlated to sound jury perceptions. A total of thirty subjects will be used for the study.

Procedures:
If you decide to be in this study, your part will involve:
You will first submit to a hearing test for screening purposes. This is an automated test, similar to those employed in public schools. After the screening, you will participate in a series of listening experiments, where you will rate recorded sounds based on your perception of the sound. There will be three experiments in total. The whole sequence of experiments will require approximately 1 hour to complete.

Risks/Discomforts
The following risks/discomforts may occur as a result of your participation in this study:
The risks involved are no greater than those involved in daily activities such as listening to music at a comfortable volume over a pair of headphones.

Benefits
The following benefits to you are possible as a result of being in this study:
You are not likely to benefit in any way from joining this study. But we hope that future flooring products will benefit from what we find in doing this study.

Compensation to You
You will be offered a US$10 gift card for Barnes and Nobles bookstore for completing the study. If a subject does not quality for the experiment, due to the screening process or that they leave in the middle of the study, they will receive a US$5 gift card for Barnes and Nobles bookstore.

Confidentiality

The following procedures will be followed to keep your personal information confidential in this study: The data that is collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB will review study records. Members of the Food and Drug Administration may also look over study records during required reviews. The Office of Human Research Protections may also look at study records.

Costs to You

There are no costs to you for participating in this study, except for your time.

Subject Rights

Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.

You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.

Any new information that may make you change your mind about being in this study will be given to you.

You will be given a copy of this consent form to keep.

You do not waive any of your legal rights by signing this consent form.

Questions about the Study or Your Rights as a Research Subject

If you have any questions about the study, you may contact Dr. K. Cunefare, at telephone (404) 894-4726).

If you have any questions about your rights as a research subject, you may contact Ms. Melanie Clark, Georgia Institute of Technology at (404) 894-6942.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

____

Subject Name

____

Subject Signature **Date**

____

Signature of Person Obtaining Consent **Date**

Georgia Institute of Technology
Project Title: Sound Quality of Laminate Flooring Systems
Investigators: James Wilson, Professor Ken Cunefare

<u>Questionnaire</u>

Research Subject Number: ____________

Male or Female? (circle one)

Are you aware of an existing hearing impairment?

YES NO (circle one)

Have you had a cold or other sinus infection/illness in the past month?

YES NO (circle one)

Do you currently live in a space with either laminate or natural wood floors?

YES NO (circle one)

Training Sounds

To complete the sound jury survey, some training is required, so that you, the subject, understand what the questionnaire is asking for. Please read the definitions below and listen to all accompanying training sounds. When completing the study, please follow the guidelines for each category as faithfully as possible.

When responding to the questionnaire, you are asked to rate each sample in five categories.

6. Naturalness
   For the naturalness category, you are asked to rate the floor for how natural you feel the sound is. Please use your previous experience with hardwood floors as the reference for this category.

7. Quality Floor
   For the quality floor category, you are asked to rate how strongly you feel the quality of the floor is based on how you perceive its sound. Please use your previous experience with hardwood floors as the reference for this category.

8. Pitch
   For the pitch category, you are asked to rate how low or how high the perceived pitch of the floor sample is. In layman's terms, pitch is how you perceive a musical note. Please take this time now to play the training sounds for pitch. You will first hear the low pitch impact three times, followed by the high impact three times. Listen as many times as you feel necessary.

9. Duration
   For the duration category, you are asked to rate how sharp or hollow the perceived duration of the floor sample is. Sharper sounds have little to no perceivable echo, while hollow sounds have a fairly high amount of perceived echo. Please take this time now to play the training sounds for duration. You will first hear the sharp impact three times, followed by the hollow impact three times. Listen as many times as you feel necessary.

10. Loudness
    For the loudness category, you are asked to rate how loud or soft the perceived loudness of the floor sample is. Please take this time now to play the training sounds for loudness. You will first hear the loud impact three times, followed by the soft impact three times. Listen as many times as you feel necessary.

Now that you have read the definitions for each category, please continue to the next page to read the instructions for the study.

Instructions (30 Samples):

For this sound jury evaluation, you are asked to listen to a pair of impact sounds created on flooring products. You will then be asked to evaluate the level of similarity between the two sounds for several categories on a descriptive response scale. Each category is listed, followed by an adjective pair. Each adjective pair consists of a descriptive adjective and its antonym. In between each adjective pair, there is a graduated scale that represents different magnitudes between each adjective pair. Choose the point on the scale, which best represents how similar you feel the second sound, "B" is to the first sound, "A" for each descriptor.

PLEASE DARKEN THE BUBBLE TO INDICATE YOUR RESPONSE.

As an example, a study created to determine the relative strength of one cup of coffee versus the strength of a second cup of coffee:

Sample 1		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Strength	Stronger	○	○	○	○	○	○	○	○	○	○	○	Weaker

You, the subject, will test each cup of coffee and then rate your impression of how similar the flavor strength of the two cups of coffee are, relative to each other.

- If the second cup of coffee is much stronger than the first cup of coffee, then you may rate the second cup as being "Very Stronger" than the first cup of coffee.
- If the second cup of coffee is only a little bit stronger than the first cup of coffee, then you may rate it as being "Barely Stronger" than the first cup of coffee.
- If you feel that the second cup of coffee is of the same strength as the first cup of coffee, then you may select "Same."

The actual study uses an evaluation form for each pair of sounds, as shown below:

Sample 1		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

When answering each comparison, use the form to complete the following statements:

The naturalness of the second sound is ___________ more artificial / more natural than the first sound.
The quality of the floor of the second sound is ___________ lower quality / higher quality than the first sound.
The pitch of the second sound is ___________ more bright / more dull than the first sound.
The duration of the second sound is ___________ more hollow / more sharp than the first sound.
The loudness of the second sound is ___________ more loud / more soft than the first sound.

When you are ready to begin the evaluation, please press "OK" on the "Testing about to begin." dialogue box.

Sample 1		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 2		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 3		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 4		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 5		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 6

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 7

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 8

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 9

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 10

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 11

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 12

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 13

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 14

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 15

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 16

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial												More Natural
Quality Floor	Lower Quality												Higher Quality
Pitch	More Bright												More Dull
Duration	More Hollow												More Sharp
Loudness	More Loud												More Soft

Sample 17

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial												More Natural
Quality Floor	Lower Quality												Higher Quality
Pitch	More Bright												More Dull
Duration	More Hollow												More Sharp
Loudness	More Loud												More Soft

Sample 18

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial												More Natural
Quality Floor	Lower Quality												Higher Quality
Pitch	More Bright												More Dull
Duration	More Hollow												More Sharp
Loudness	More Loud												More Soft

Sample 19

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial												More Natural
Quality Floor	Lower Quality												Higher Quality
Pitch	More Bright												More Dull
Duration	More Hollow												More Sharp
Loudness	More Loud												More Soft

Sample 20

		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial												More Natural
Quality Floor	Lower Quality												Higher Quality
Pitch	More Bright												More Dull
Duration	More Hollow												More Sharp
Loudness	More Loud												More Soft

Sample 21		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 22		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 23		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 24		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 25		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 26		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 27		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 28		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 29		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

Sample 30		Extremely	Very	A Lot	Somewhat	Barely	Same	Barely	Somewhat	A Lot	Very	Extremely	
Naturalness	More Artificial	○	○	○	○	○	○	○	○	○	○	○	More Natural
Quality Floor	Lower Quality	○	○	○	○	○	○	○	○	○	○	○	Higher Quality
Pitch	More Bright	○	○	○	○	○	○	○	○	○	○	○	More Dull
Duration	More Hollow	○	○	○	○	○	○	○	○	○	○	○	More Sharp
Loudness	More Loud	○	○	○	○	○	○	○	○	○	○	○	More Soft

THANK YOU FOR PARTICIPATING IN THE STUDY!

Appendix VIII: IRB documents.

Appendix VIII-1: Proposal Routing.

GEORGIA INSTITUTE OF TECHNOLOGY
SPONSORED PROGRAMS/RESEARCH PROPOSAL AUTHORIZATION ROUTING FORM

DEPT./LAB PROPOSAL TRACKING NUMBER	FOR OSP USE ONLY:

INVESTIGATOR DATA

PROJECT DIRECTOR/PRINCIPAL INVESTIGATOR (DR./MR./MRS./MISS/MS.) DR. KENNETH A. CUNEFARE	PHONE 404-894-4726	CAMPUS ADDRESS & MAIL CODE MECHANICAL ENGINEERING 0405
E-MAIL KEN.CUNEFARE@ME.GATECH.EDU	FAX 404-894-7790	
LABORATORY, CENTER, COLLEGE OR SCHOOL MECHANICAL ENGINEERING		
CO-PD/PI (S)		
ADMINISTRATIVE COORDINATOR, IF OTHER THAN PD/PI	PHONE	CAMPUS ADDRESS & MAIL CODE
E-MAIL	FAX	

PROPOSAL DATA

PROPOSAL TITLE

PROPOSAL/AWARD CLASSIFICATION:
☒ NEW ☐ REVISED BUDGET FOR ___________________
☐ CONTINUATION/RENEWAL OF ___________________ ☐ OTHER REVISION OF ___________________
☐ SUPPLEMENT TO ___________________
IF THIS IS A CONTINUATION OR RENEWAL, DOES THIS PROPOSAL CONTAIN AN ANNUAL OR INTERIM REPORT REQUIRED BY THE EXISTING AGREEMENT? **Yes** ☐ **No** ☐
☐ REQUEST FOR PROPOSAL/APPLICATION (RFP, RFA) NUMBER ___________________

TYPE OF AWARD (CONTRACT TYPE):
☒ COST REIMBURSEMENT NO FEE (DEFAULT - RESIDENT INSTRUCTION)
☐ COST REIMBURSEMENT WITH A FEE (DEFAULT - GTRI)
☐ TIME & MATERIALS CONTRACT (MEMO REQUIRED)
☐ FIXED PRICE CONTRACT (MEMO REQUIRED – RESIDENT INSTRUCTION)

COST SHARING

YES	NO	
☐	☒	IS COST SHARING PROPOSED? (ATTACH APPROVAL FORM)
☐	☒	IS COST SHARING CONTRACTUALLY REQUIRED BY THE SPONSOR?

TOTAL $ PROPOSED	ESTIMATED START DATE	DUE DATE & TIME	PERFORMANCE PERIOD MONTHS:_____ OR DAYS: ______

KEY WORDS (AT LEAST ONE REQUIRED) :

SPONSOR DATA

SPONSORING ORGANIZATION NAME (FUNDING ORGANIZATION OR THE SUBAWARD IS FROM) SEALED AIR CORPORATION	SPONSOR'S TECHNICAL CONTACT SCOTT LAMBERT	
	PHONE 864 433 3129	EMAIL Scott.Lambert@sealedair.com
MAILING ADDRESS OF SPONSORING ORGANIZATION	ADMINISTRATIVE CONTACT	
	PHONE	EMAIL
NAME OF SPONSORING GOVERNMENT ORGANIZATION (PRIME), IF APPLICABLE PRIME CONTRACT NUMBER:	SOURCE OF FUNDS, IF DIFFERENT FROM SPONSORING ORGANIZATION OR PRIME CONTRACT NUMBER FOR SOURCE OF FUNDS:	
CHECK PREFERRED MAILING METHOD. ☐ ELECTRONIC – EMAIL OR FAX IF APPLICABLE:___________________ ☐ EXPRESS COURIER ☐ FIRST CLASS CERTIFIED ☐ U.S. EXPRESS MAIL	COURIER (HAND DELIVERY) ADDRESS	
SHIPPING ACCOUNT TO BE CHARGED:		

SPECIAL REVIEW CHECKLIST

The proposal submitted involves the following:

Yes	No	
☐	☒	Human Subject Research IRB protocol Number: ___________________ Expiration Date: ______________
☐	☒	Vertebrate Animals IACUC protocol Number: ___________________ Expiration Date: ______________
☐	☒	Recombinant DNA IBC protocol Number: ___________________ Expiration Date: ______________
		Applicants may request a deferral to submit a funding proposal without an approved protocol as required by GT policy. Requests must be made in writing to your Contracting Officer who will obtain institutional approval for such action. ***NOTE:** No awards will be accepted without an approved GT protocol in place.*
☐	☒	Select Agents See list at www.cdc.gov/od/sap/docs/salist.pdf More info: www.cdc.gov/od/sap/
☐	☒	Biological Agents: Check all that apply: ☐ Infectious or Pathogenic agent(s) ☐ Human tissues or bodily fluid(s) ☐ Other Bio materials
☐	☒	Physical Agents: Check all that apply: ☐ Chemicals ☐ Sharps ☐ Laser ☐ Radiation ☐ Thermal agent(s)
☐	☒	Materials Transfer Agreement (MTA)
☐	☒	Professional Education Program (if yes, please route form to DLPE)
☐	☒	Subaward(s) are proposed
☐	☒	Teaming Agreement
☐	☒	Research may result in an export of information or material to another country (ITAR/EAR)
☐	☒	Involves the use of specific results IP from previous research – explain in comments section.
☐	☐	Non-Disclosure Agreement (NDA) is required or in process

Appendix VIII-2: Statement of Work.

Standardized Test Method for the Sound Quality of Laminate Flooring
Submitted to Sealed Air, Inc
August 30, 2007

Statement of Work

The project will focus on the development of a test method to create impact sound and measure in-room frequency distribution (pitch) for laminate floors with different types of commercially available underlaminates and subfloors. The basic method will incorporate flooring and subfloor configurations installed in the GIT hemi-anechoic room and a mechanism for generating an impact at some point on the flooring. Time data of the acoustic response of the floor to the impact will be recorded on at least one channel. In addition, surface motion may be recorded. The data will be analyzed in the time and frequency domain to determine suitable metrics of "quality" appropriate to flooring impact sounds. The deliverables are:

1. Recommendation and specification of equipment necessary to implement the test method at SAC.
2. Results of measurements on commercial products supplied by SAC.

Budget

Direct costs are burdened with overhead at 55.7%.

DOMESTIC TRAVEL	3000
OTHER DIRECT COSTS	
MATERIALS AND SUPPLIES	10000
TOTAL DIRECT COSTS)	13000
INDIRECT COSTS (55.7% of direct)	
TOTAL INDIRECT COSTS	7241
TOTAL DIRECT AND INDIRECT	20241

Appendix VIII-3: Abstract.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Abstract:
The laminate flooring industry identifies the ability of a laminate floor to recreate the sound of traditional hardwood floors as an important metric for their perceived quality. Research is conducted to develop a set of sound quality metrics that objectively quantify the ability of laminate flooring systems to create this natural sound. In order for objective lab measurements to be correlated to human-perceived sound quality, a sound jury study must be performed. The study has jury subjects listen to recorded impact sounds on various flooring systems. The jury then rates their perceived reactions on a subjective scale. A sample size of 50 individuals will be used for the experiment.

Appendix VIII-4: Abstract.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Confidentiality Statement:
Each set of data and questionnaire will be assigned a number with which no name is associated. The consent form is the only document containing the names of the subjects which is stored separately in a locked drawer in the office.

Appendix VIII-5: Exclusion Criteria.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Inclusion/Exclusion Criteria:
Subjects will be recruited from Georgia Institute of Technology student population. One group of people will be explicitly excluded in the study: subjects with “non-normal” hearing. The screening audiogram quantifies a subjects hearing loss in terms of dB hearing loss, or dBHL across the frequency range of human hearing. Normal hearing is classified as being between -10dBHL and 15dBHL. A subject who falls outside of this envelope will not qualify for the study. They will still receive a $5 gift card for participation up to this point. The audiogram is an automated system, and the determination of normal hearing is 100% objective. The audiogram is administered by co-investigator James Wilson.

Several groups are potentially vulnerable. Economically disadvantaged group may be at a disadvantage since this research would require the use of a computer which may not be available to them. However, the disadvantage is insignificant since the tasks to be performed are based more on eye-hand coordination and tactile sensation than on computer knowledge. Given that the subjects will be recruited from Georgia Institute of Technology, it is safe to assume those who do not own a computer can easily access one on-campus. Non-native English speakers may be at a disadvantage since the instructions and paperwork used during the study will be in English. However, it is safe to assume that students admitted into Georgia Institute of Technology at least understands English as a second language, in which case the investigator will instruct the subjects thoughtfully. Certain illness that affects an individual's hearing may put him or her at a disadvantage, in which case he or she is not eligible for this study. We do not expect to have pregnant women participating in this study. However they are certainly eligible as our laboratory provides ample seating. Since students will be used for this study, there is a chance that he or she may have studied under the investigator. This may produce a psychological effect that may affect performance.

Appendix VIII-6: Lay Summary.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Lay Summary

The laminate flooring industry identifies the ability of a laminate floor to recreate the sound of traditional hardwood floors as an important metric for their perceived quality and acceptance. The market describes the inability of laminate flooring to reproduce the natural sound of wood as a drawback to their market appeal. Therefore, if a laminate flooring composite can be offered to the market which recreates the natural wood floor acoustic experience, the floor will offer additional value to the consumer. Products on the market today exist, which do improve the sound quality of laminate flooring composites. However, there is no unified standard to justify or prove marketing claims made by manufacturers. Previous attempts to quantify the subjective differences of the sound quality of the floors were unsuccessful, when the quantitative metrics were measured against a sound jury. However, these attempts focused on spectral content of the signal, alone.

In the area of psychoacoustics, many additional metrics exist to describe the human perception of sound, which aids in describing sound quality. These metrics can be utilized to characterize the sound of traditional hardwood floors and laminate systems, beyond what has been done in previous work. By employing these metrics, and then correlating them to subjective sound jury perception, it is possible to better predict the sound quality of a laminate floor. The sound jury will show which metrics are relevant to the characterization of sound of these flooring systems.

Appendix VIII-7: Protocol Description.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Protocol Description:
First the subject will be asked to fill out a short questionnaire. The questionnaire will ask about the subject's age, gender, impairments relevant to their hearing, and their experience with this family of products. Then he or she will be introduced to the listening hardware (headphones, amplifier, etc) involved in the study. These devices are similar to hardware found in home audio equipment, both in form and function. The user will wear the headphones, while listening to recordings played over the equipment.

The subject will first undergo an audiogram, which is simply a standard hearing test. The audiogram shows whether the subject has "normal" hearing or not. The screening audiogram is an automated system. The audiogram quantifies a subjects hearing loss in terms of dB hearing loss, or dBHL across the frequency range of human hearing. Normal hearing is classified as being between -10dBHL and 15dBHL. A subject who falls outside of this envelope will not qualify for the study. This determination is 100% objective. After the qualifying audiogram, the experiment begins.

The subject will listen to a series of recorded sounds, and rate their relative characteristics. For example, a subject will be asked to rate the loudness of each sound on a scale of 1 – 9. At the end of the scaling, they then write down their own description for their rating scale. The procedure will be repeated for other sound descriptors, such as hollowness, fullness, richness, sharpness, etc.

The second task involves listening to the same sounds and rating their perception of the sound as that of a quality floor. The same 1 – 9 relative rating system will be used.

The third task involves listening to the same sounds and rating their perception of the sound as that of a natural sounding floor. The same 1 – 9 relative rating system will be used.

Additionally, paired comparison tasks will be asked of the subject. In a paired comparison, the subject listens to two sounds and records how they sound relative to each other. For example, 2 sounds are played and the subject records which sound they perceive as having a higher pitch.

Appendix VIII-8: Recruitment.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Recruitment:
The recruitment plan involves both word of mouth and ads. Flyers will be distributed in before and after classes in Georgia Institute of Technology. A copy of the flyer is attached. From there the study will spread by the word of mouth. Sign up is on first come first serve basis via e-mail.

Each subject will be offered a US$10 gift card for Barnes and Nobles bookstore for completing the study. Should they choose to leave in the middle of the study for any reason or if they are screened by the audiogram, they will receive a US$5 gift card for Barnes and Nobles bookstore.

Verbal Recruitment Script:
We are conducting a sound jury to evaluate the sound quality of laminate hardwood flooring systems. As a result, we are recruiting students to participate in this sound jury. To participate in the study, you will first take a qualifying audiogram, which is standard hearing test. The test is automatically administered and the results are pass/fail. Afterwards, you will listen subjectively rate the sound quality of different flooring systems. All of the audiogram and sound jury testing will be performed by a computer over headphones. A $10 gift card to Barnes and Noble bookstore will be provided for your participation. If you participate, but are unable to complete the survey for any reason, you will receive a $5 gift card to Barnes and Noble bookstore. The testing will take approximately two hours of your time.

Appendix VIII-9: Advertisement.

Student's Needed!
Psychoacoustics Study

Participate in a Sound Jury

Who: Any GT Student

What: Psychoacoustics Sound Jury

When: By Appointment (approx. 2 hrs)

$10 Gift Card for Completing Study

Contact:
jwilson60@mail.gatech.edu

Appendix VIII-10: Risk / Benefit Statement.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Risk/Benefit Statement:
The risks involved are no greater than those involved in daily activities such as listening to music over headphones at a comfortable level. Safety is insured in this experiment. The audio hardware is a commercially available off the shelf device used extensively in industry. All recordings will be played at a level safe for listening.

The subjects are not likely to benefit in any way from joining this study.

Appendix VIII-11: Scientific Methodology.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Scientific Methodology:
Attempts have been made this to make this study as scientifically objective as possible. In all tasks, there will be a training period consisting of a dry run, so that the subject becomes comfortable with the protocol and ask questions. The subject will learn primarily by doing it; input from the investigator will be kept at a minimum except in cases where device operation itself and safety is concerned. Each run of the task will be similar but not identical as noted below.

The audiogram ensures that subjects are within the "normal" limits for human hearing. This screening will ensure that results are not skewed by erroneous data stemming from hearing loss.

In the first task, subjects will listen to a series of sounds and rate them. The sounds will be rated based on how the sound fits adjective descriptors, such as not loud / very loud, not sharp / very sharp. In order to quantify the result, a rating system from 1 – 9 allows subjects to assign a degree of one or the other.

The second task follows the same methodology, but the subjective measurement will simply be the perceived quality of the floor.

The third task is also the same, but the subjective measurement will simply be the perceived naturalness of the sound of the floor.

Additionally, paired comparison tasks will be asked of the subject. In a paired comparison, the subject listens to two sounds and records how they sound relative to each other. For example, 2 sounds are played and the subject records which sound they perceive as having a higher pitch.

After the human testing is completed, the responses will be correlated with the numerical qualities calculated, which also describe the sound of the floor. Statistics will be used to correlate the dependencies of the numerical qualities with the subjective perceptions obtained in the human study.

Appendix VIII-12: Sealed Air Corporation Recruitment.

Protocol Title: Sound Quality of Laminate Flooring Systems

Investigators: James Wilson (jwilson60@mail.gatech.edu), Professor Ken Cunefare (ken.cunefare@me.gatech.edu).

Recruitment:
The Sealed Air Corporation, who is sponsoring the project, has agreed to participate in the second study. They will aid in the recruitment of the sound jury subjects at their facility. Testing of these subjects will be performed at the Sealed Air Corporation facility.

The recruitment plan involves both word of mouth and ads. Flyers will be posted at the Sealed Air Corporation facility in Duncan, SC. A copy of the flyer is attached. Additionally, the study will spread by the word of mouth. Sign up is on first come first serve basis via e-mail.

Each subject will be offered a US$10 gift card for Barnes and Nobles bookstore for completing the study. Should they choose to leave in the middle of the study for any reason or if they are screened by the audiogram, they will receive a US$5 gift card for Barnes and Nobles bookstore.

Verbal Recruitment Script:
We are conducting a sound jury to evaluate the sound quality of laminate hardwood flooring systems. As a result, we are recruiting employees to participate in this sound jury. To participate in the study, you will first take a qualifying audiogram, which is standard hearing test. The test is automatically administered and the results are pass/fail. Afterwards, you will subjectively rate the sound quality of different flooring systems. All of the audiogram and sound jury testing will be performed by a computer over headphones. A $10 gift card to Barnes and Noble bookstore will be provided for your participation. If you participate, but are unable to complete the survey for any reason, you will receive a $5 gift card to Barnes and Noble bookstore. The testing will take approximately one hour of your time.

Appendix VIII-13: Sealed Air Corporation Advertisement.

Subjects Needed!
Psychoacoustics Study

Participate in a Sound Jury

Who: Any SAC Associate
What: Psychoacoustics Sound Jury
When: By Appointment (approx. 1 hr)

$10 Gift Card for Completing Study

Contact:
jwilson60@mail.gatech.edu

Appendix VIII-14: Sealed Air Corporation Approval Email.

Jamie,
Sealed Air is in agreement that you can conduct your research on our premises. Additionally we agree that you can recruit your subject pool from our associates and that they can participate in the study if they agree to do so.

Scott

____

Scott Lambert
Manager - Technology and Innovation
Sealed Air Corporation
Cryovac Division
100 Rogers Bridge Rd., Bldg. A
Duncan, SC 29334
864-433-3129

____

"James Wilson" <jwilson60@mail.gatech.edu>

To <Scott.Lambert@sealedair.com>
Subject SAC permission request.

Please respond back to this email with an affirmative that it is OK for me (James Wilson) to conduct the Georgia Tech research project, sponsored by Sealed Air Corporation in Duncan, SC, on the premises of Sealed Air.

Scott,

As we discussed in our meeting on August 8, 2008 and again on August 12, 2008, Sealed Air agrees to participate in the Sound Quality of Laminate Flooring study (IRB Protocol: H08107). Sealed Air Corporation agrees to allow us use of a conference room at the Duncan, SC campus. Additionally, Sealed Air Corporation agrees to allow us to recruit the subject pool from Sealed Air associates. Sealed Air agrees to allow their associates to participate in the study during regular business hours on company time.

Thank you for your help and participation.

Jamie Wilson
jwilson60@mail.gatech.edu
404-403-2348

Appendix IX: MATLAB Code.

Appendix IX -1: MATLAB .wav conversion code.

```
clear;
close all;

[data,data1path] = uigetfile('*.m','Select the File');
root = data(1:end-2); % file name
data = load(data);

LMSs = 25600;
Fs = 48000;

t = data(:,1); % time data
p = data(:,2); % pressure data

y = p/20;

%[y,range] = wavscale(p);

x = resample(p,Fs,LMSs)/20;

%wavwrite(y,LMSs,[root]);
wavwrite(x,Fs,[root,'48k']);

fprintf('File: %s \n', root)
%fprintf('  Gain = %6.3f \n', range)
```

Appendix IX-2(a): MATLAB psychoacoustic metric code.

```
clear;
close all;

[data,data1path] = uigetfile('*.m','Select the File');
root = data(1:end-3); % file name
data = load(data);

t = data(:,1); % time data
p = data(:,2); % pressure data

LMSs = 25600; % LMS sampling rate
Fs = 48000; % resample rate for 1/3 octave filters

[f,Pmag,dB] = fftdB1(p,LMSs);

[SFM, T] = spec_flatness(Pmag);

x = resample(p,Fs,LMSs);

[Ptotal,P,N_entire,N_single,sharp] = psychoacoustics(x,Fs);

fprintf('File: %s\n', root)
fprintf('Sound Pressure Level = %6.3f dB\n', Ptotal)
fprintf('Loudness = %6.3f Sone\n', N_entire)
fprintf('Sharpness = %6.3f acum\n', sharp)
fprintf('Spectral Flatness Measure = %6.3f\n', SFM)
fprintf('Tonality ~ %6.3f\n', T)
```

Appendix IX-2(b): MATLAB fftdB1 function.

```
function [f,Pmag,dB] = fftdB1(y,Fmax)


fftbar = length(y); %# of data points on the fft plot
fftbars = fftbar*2; %2x # of data points on the fft plot (due to
imaginary data discard)
f = Fmax*2*(0:(fftbars-1))/fftbars;
f = f(1:(end));

Pmag=abs(fft(y,fftbars)); %compute abs value pressure fft of data
Pmag=Pmag(1:(end)); %throw away non real dB data
dB = 20*log10(Pmag); %convert to dB scale

figure(6);
plot(f,dB);
axis([0 12500 0 (max(dB)+10)]);
ylabel('SPL [dB]')
xlabel('Frequency [Hz]')


figure(5);
plot(f,Pmag);
axis([0 12500 0 (max(Pmag)+10)]);
ylabel('SPL [dB]')
xlabel('Frequency [Hz]')
```

Appendix IX-2(c): MATLAB spec_flatness function.

```
function [SFM, T] = spec_flatness(Pmag)

% Sectral Flatness Measure
% ********************************************************
% Calculates the spectral flatness of a signal 10*log(geometric mean /
%arithmetic mean)
http://www.temple.edu/speech_lab/IEEE_WISP_2001_V5.PDF
% Pmag = pressure magnitude spectrum
% SFM = spectral flatness measure  [dimentionless dB]
%********************************************************
% James Wilson Feb. 2008

gm = sum(log(Pmag(1:end)))/length(Pmag);
am = mean(Pmag(1:end));

SFM = gm/am;
T = 1/SFM;
```

Appendix IX-2(d): MATLAB psychoacoustics function.

```
function [Ptotal, P, N_entire, N_single, sharp, SFM, T] =
psychoacoustics(x, Fs)

Pref = 20;
Mod = 0;
Fmin = 25;
Fmax = 12500;
N = 4;

[Ptotal,P,F]=filter_third_octaves_downsample(x,Pref,Fs,Fmin,Fmax,N);

[N_entire,N_single] = loudness_1991(x, Pref, Fs, Mod);

[sharp] = sharpness_Fastl(N_single);
```

Appendix IX-2(e): MATLAB filter_third_octaves_downsample function.

```
function [Ptotal, P, F] = filter_third_octaves_downsample(x, Pref, Fs,
Fmin, Fmax, N)

% Calls the octave design function for each of the octave bands
% x is the file (Input length must be a multiple of 2^8)
% Pref is the reference level for calculating decibels
% Fmin is the minimum frequency
% Fmax is the maximum frequency (must be at least 2500 Hz)
% Fs is the sampling frequency
% N is the filter order

%**********************************************************************
*****************
% PART 1
%fprintf('PART 1: Calculates the frequency midbands(ff), corresponding
nominal frequecies(F) and indices(i)\n')
%**********************************************************************
*****************
[ff, F, j] = midbands(Fmin, Fmax, Fs);

%**********************************************************************
*****************
% PART 2A
%fprintf('PART 2A: Designs and implements the filters, computing the
RMS levels in each 1/3-oct. band\n')
%**********************************************************************
*****************

P = zeros(1,length(j));
k = find(j==7); % Determines where downsampling will commence (5000 Hz
and below)
m = length(x);

% For frequencies of 6300 Hz or higher, direct implementation of
filters.
for i = length(j):-1:k+1;
    [B,A] = filter_design2(ff(i),Fs,N);
    if i==k+3; % Upper 1/3-oct. band in last octave.
        Bu=B;
        Au=A;
    end
    if i==k+2; % Center 1/3-oct. band in last octave.
        Bc=B;
        Ac=A;
    end
    if i==k+1; % Lower 1/3-oct. band in last octave.
        Bl=B;
        Al=A;
    end
    y = filter(B,A,x);
    P(i) = 20*log10(sqrt(sum(y.^2))); % Convert to decibels.
end
```

```
% 5000 Hz or lower, multirate filter implementation.
try
    for i = k:-3:1;
          % Design anti-aliasing filter (IIR Filter)
        Wn = 0.4;
        [C,D] = cheby1(2,0.1,Wn);
          % Filter
        x = filter(C,D,x);
          % Downsample
        x = downsample(x,2,1); % Offset by one to eliminate end effects
        Fs = Fs/2;
        m = length(x);
          % Performs the filtering
        y = filter(Bu,Au,x);
        P(i) = 20*log10(sqrt(sum(y.^2)));
        y = filter(Bc,Ac,x);
        P(i-1) = 20*log10(sqrt(sum(y.^2)));
        y = filter(Bl,Al,x);
        P(i-2) = 20*log10(sqrt(sum(y.^2)));
    end
catch
    error = lasterr
    P = P(1:length(j));
end

%**********************************************************************
******************
% PART 3
%fprintf('PART 3: Calibrates the readings\n')
%**********************************************************************
******************

P = P + Pref;               % Reference level for dB scale, from
calibration run.

%**********************************************************************
******************
% PART 4
%fprintf('PART 5: Generates a plot of the powers within each frequency
band\n')
%**********************************************************************
******************

figure(2)
bar(P);
%axis([0 (length(F)+1) (-10) (max(P)+1)])
set(gca,'XTick',[1:3:length(P)]);
set(gca,'XTickLabel',F(1:3:length(F))); % Labels frequency axis on
third octaves.
xlabel('Frequency band [Hz]'); ylabel('Powers [dB]');
title('One-third-octave spectrum')

Plog = 10.^(P./10);
Ptotal = sum(Plog);
Ptotal = 10*log10(Ptotal);
```

Appendix IX-2(f): MATLAB loudness_1991 function.

```
function [N_entire,N_single] = loudness_1991(x, Pref, Fs, Mod)

% LOUDNESS
% ********************************************************
% based on ISO 532 B / DIN 45 631
% Source: BASIC code in J Acoust Soc Jpn (E) 12, 1 (1991)
% x = signal
% Pref = refernce value [dB]
% Fs = sampling frequency [Hz]
% Mod = 0 for free field
% Mod = 1 for diffuse field
% N_entire = entire loudness [sone]
% N_single = partial loudness  [sone/Bark]
%*********************************************************
% Claire Churchill Jun. 2004

%**********************************************************************
*****************
% PART 1
%fprintf('PART 1:Filters the data with Butterworth 1/3 octave filters
of steepness N=4\n')
%**********************************************************************
*****************

%'Generally used third-octave band filters show a leakage towards
neighbouring filters of about
% -20dB. This means that a 70dB, 1-kHz tone produces the following
levels at different centre
% frequencies: 10dB at 500 Hz, 30dB at 630Hz, 50dB at 800Hz and 70dB at
1kHz.'
% P211 Psychoacoustics: Facts and Models, E. Zwicker and H. Fastl
% (A filter order of 4 gives approx this result)

Fmin = 25;
Fmax = 12500;
order = 4;
[Ptotal, P, F] = filter_third_octaves_downsample(x, Pref, Fs, Fmin,
Fmax, order);

%
***********************************************************************
******
% PART 2: line 1480
%fprintf('PART 2: A list of the constants\n')
%
***********************************************************************
******

% Centre frequencies of 1/3 Oct bands (FR)
FR = [25 31.5 40 50 63 80 100 125 160 200 250 315 400 500 630 800 1000
1250 ...
        1600 2000 2500 3150 4000 5000 6300 8000 10000 12500];
```

```
% Ranges of 1/3 Oct bands for correction at low frequencies according
to equal loudness contours
RAP = [45 55 65 71 80 90 100 120];

% Reduction of 1/3 Oct Band levels at low frequencies according to
equal loudness contours
% within the eight ranges defined by RAP (DLL)
DLL = [-32 -24 -16 -10 -5 0 -7 -3 0 -2 0;
    -29 -22 -15 -10 -4 0 -7 -2 0 -2 0;
    -27 -19 -14 -9 -4 0 -6 -2 0 -2 0;
    -25 -17 -12 -9 -3 0 -5 -2 0 -2 0;
    -23 -16 -11 -7 -3 0 -4 -1 0 -1 0;
    -20 -14 -10 -6 -3 0 -4 -1 0 -1 0;
    -18 -12 -9 -6 -2 0 -3 -1 0 -1 0;
    -15 -10 -8 -4 -2 0 -3 -1 0 -1 0];

% Critical band level at absolute threshold without taking into account
the
% transmission characteristics of the ear
LTQ = [30 18 12 8 7 6 5 4 3 3 3 3 3 3 3 3 3 3 3 3]; % Threshold due to
internal noise
% Hearing thresholds for the excitation levels (each number corresponds
to a critical band 12.5kHz is not included)

% Attenuation representing transmission between freefield and our
hearing system
A0  = [0 0 0 0 0 0 0 0 0 0 -.5 -1.6 -3.2 -5.4 -5.6 -4 -1.5 2 5 12]; %
Attenuation due to transmission in the middle ear
% Moore et al disagrees with this being flat for low frequencies

% Level correction to convert from a free field to a diffuse field
(last critical band 12.5kHz is not included)
DDF = [0 0 .5 .9 1.2 1.6 2.3 2.8 3 2 0 -1.4 -2 -1.9 -1 .5 3 4 4.3 4];

% Correction factor because using third octave band levels (rather than
critical bands)
DCB = [-.25 -.6 -.8 -.8 -.5 0 .5 1.1 1.5 1.7 1.8 1.8 1.7 1.6 1.4 1.2 .8
.5 0 -.5];

% Upper limits of the approximated critical bands
ZUP  = [.9 1.8 2.8 3.5 4.4 5.4 6.6 7.9 9.2 10.6 12.3 13.8 15.2 16.7
18.1 19.3 20.6 21.8 22.7 23.6 24];

% Range of specific loudness for the determination of the steepness of
the upper slopes in the specific loudness
% - critical band rate pattern (used to plot the correct USL curve)
RNS = [21.5 18 15.1 11.5 9 6.1 4.4 3.1 2.13 1.36 .82 .42 .30 .22 .15
.10 .035 0];

% This is used to design the right hand slope of the loudness
USL = [13 8.2 6.3 5.5 5.5 5.5 5.5 5.5;
   9   7.5 6   5.1 4.5 4.5 4.5 4.5;
   7.8 6.7 5.6 4.9 4.4 3.9 3.9 3.9;
   6.2 5.4 4.6 4.0 3.5 3.2 3.2 3.2;
```

```
    4.5 3.8 3.6 3.2 2.9 2.7 2.7 2.7;
    3.7 3.0 2.8 2.35 2.2 2.2 2.2 2.2;
    2.9 2.3 2.1 1.9 1.8 1.7 1.7 1.7;
    2.4 1.7 1.5 1.35 1.3 1.3 1.3 1.3;
    1.95 1.45 1.3 1.15 1.1 1.1 1.1 1.1;
    1.5 1.2 .94 .86 .82 .82 .82 .82;
    .72 .67 .64 .63 .62 .62 .62 .62;
    .59 .53 .51 .50 .42 .42 .42 .42;
    .40 .33 .26 .24 .24 .22 .22 .22;
    .27 .21 .20 .18 .17 .17 .17 .17;
    .16 .15 .14 .12 .11 .11 .11 .11;
    .12 .11 .10 .08 .08 .08 .08 .08;
    .09 .08 .07 .06 .06 .06 .06 .05;
     .06 .05 .03 .02 .02 .02 .02 .02];

%***********************************************************************
**************************
% PART 3A: line
%fprintf('PART 3A: Adds a weighting factor to the first three 1/3
octave bands\n')
%***********************************************************************
**************************

for i=1:11;
    j=1;
    while (P(i) > (RAP(j)-DLL(j,i))) & (j < 8);
        j=j+1;
    end
    Xp(i) = P(i) + DLL(j,i);
    Ti(i) = 10^(Xp(i)/10);
end

% Outputs Xp = reduced levels, Ti = reduced third octave intensities

%***********************************************************************
**************************
% PART 3B: line
%fprintf('PART 3B: Intensity calculated for 1/3 octave bands four to
eleven\n')
%***********************************************************************
**************************

% (see above)
% Output Ti = third octave intensities

%***********************************************************************
**************************
% PART 4: line
%fprintf('PART 4: Intensity values in first three critical bands
calculated\n')
%***********************************************************************
**************************

Gi(1) = sum(Ti([1:6])); % Gi(1) is the first critical band (sum of two
octaves (25Hz to 80Hz))
```

```
Gi(2) = sum(Ti([7:9])); % Gi(2) is the second critical band (sum of
octave (100Hz to 160Hz))
Gi(3) = sum(Ti([10:11])); % Gi(3) is the third critical band (sum of
two third octave bands (200Hz to 250Hz))

FNGi = 10*log10(Gi);

for i=1:3;
    if Gi(i)>0;
        LCB(i) = FNGi(i);
    else
        LCB(i) = 0;
    end
end

%*********************************************************************
***************************
% PART 5: line
%fprintf('PART 5: Calculates the main loudness in each critical
band\n')
%*********************************************************************
***************************

for i = 1:20;
    Le(i) = P(i+8);
    if i <= 3;
        Le(i) = LCB(i);
    end
    Lk(i) = Le(i) - A0(i);
    Nm(i) = 0;
    if Mod == 1;
        Le(i) = Le(i) + DDF(i);
    end
    if Le(i) > LTQ(i);
        Le(i) = Lk(i) - DCB(i);
        S = 0.25;
        MP1 = 0.0635 * 10^(0.025*LTQ(i));
        MP2 = (1 - S + S*10^(0.1*(Le(i)-LTQ(i))))^0.25 - 1;
        Nm(i) = MP1*MP2;
        if Nm(i)<=0;
            Nm(i)=0;
        end
    end
end
Nm(21) = 0;

KORRY = .4 + .32*Nm(1)^.2;
if KORRY > 1;
    KORRY=1;
end

Nm(1) = Nm(1)*KORRY;

%*********************************************************************
*****************************
```

```
% PART 6: line 6060
%fprintf('PART 6: Adds the masking curves to the main loudness in each
third octave band\n')
%***********************************************************************
*****************************

N = 0;
z1 = 0; % critical band rate starts at 0
n1 = 0; % loudness level starts at 0
j = 18;
iz = 1;
z = 0.1;

for i = 1:21

% Determines where to start on the slope
   ig = i-1;
   if ig >8;
       ig=8;
   end
   control=1;
   while (z1 < ZUP(i)) | (control==1) % ZUP is the upper limit of the
approximated critical band

% Determines which of the slopes to use
      if n1 < Nm(i),      % Nm is the main loudness level
         j=1;
         while RNS(j) > Nm(i), % the value of j is used below to build
a slope
            j=j+1; % j becomes the index at which Nm(i) is first
greater than RNS
         end
      end

% The flat portions of the loudness graph
      if n1 <= Nm(i),
         z2 = ZUP(i); % z2 becomes the upper limit of the critical band
         n2 = Nm(i);
         N = N + n2*(z2-z1); % Sums the output (N_entire)
         for k = z:0.1:z2      % k goes from z to upper limit of the
critical band in steps of 0.1
            ns(iz) = n2; % ns is the output, and equals the value of Nm
            if k < (z2-0.05),
               iz = iz + 1;
            end
         end
         z = k; % z becomes the last value of k
         z = round(z*10)*0.1;
      end

% The sloped portions of the loudness graph
      if n1 > Nm(i),
          n2 = RNS(j);
          if n2 < Nm(i);
              n2 = Nm(i);
          end
```

```
            dz = (n1-n2)/USL(j,ig); % USL = slopes
            dz = round(dz*10)*0.1;
            if dz == 0;
                dz = 0.1;
            end
            z2 = z1 + dz;
            if z2 > ZUP(i),
               z2 = ZUP(i);
               dz = z2-z1;
               n2 = n1 - dz*USL(j,ig); %USL = slopes
            end
            N = N + dz*(n1+n2)/2; % Sums the output (N_entire)
            for k = z:0.1:z2
              ns(iz) = n1 - (k-z1)*USL(j,ig); % ns is the output, USL =
slopes
              if k < (z2-0.05),
                 iz = iz + 1;
              end
            end
            z = k;
            z = round(z*10)*0.1;
         end
         if n2 == RNS(j);
             j=j+1;
         end
         if j > 18;
             j = 18;
         end
         n1 = n2;
         z1 = z2;
         z1 = round(z1*10)*0.1;
         control = control+1;
   end
end

if N < 0;
    N = 0;
end

if N <= 16;
    N = floor(N*1000+.5)/1000;
else
    N = floor(N*100+.5)/100;
end

LN = 40*(N + .0005)^.35;

if LN < 3;
    LN = 3;
end

if N >= 1;
    LN = 10*log10(N)/log10(2) + 40;
end

for i=1:240;
```

```
    N_single(i) = ns(i);
end

N_entire = N;

%**********************************************************************
********
% PART 8
%fprintf('PART 7 : Figure\n')
%**********************************************************************
********


figure(3);
x=[.1:.1:24];
plot(x,N_single,'-');
grid on
axis([0 24 0 (max(N_single)+1)]);
ylabel('N´ [sone/Bark]')
xlabel('z [Bark]')
```

Appendix IX-2(g): MATLAB sharpness_Fastl function.

```
function [sharp] = sharpness_Fastl(loudspec)

% SHARPNESS
%*****************************************************************
% Method FASTL (1991)
% Expression for weighting function obtained by fitting an
% equation to data given in 'Psychoacoustics: Facts and Models'
% using MATLAB basic fitting function
% sharp = sharpness [acum]
%*****************************************************************
% Claire Churchill Sep 2004

n = length(loudspec);

gz(1:140) = 1;
z = 141:n;
gz(z) = 0.00012*(z/10).^4-0.0056*(z/10).^3+0.1*(z/10).^2-
0.81*(z/10)+3.5;

z = 0.1:0.1:(n/10);

sharp = 0.11 * sum(loudspec.*gz.*z.*0.1) / sum(loudspec.*0.1);
```

REFERENCES

1. FloorOne.com. *Flooring Underlayment - Types and Uses*. [cited; Available from: http://www.floorone.com/informative/laminate/underlayment.asp.
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